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Alan W. White

Biological Station
St. Andrews, N.B., E0G 2X0

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by

Alan W. White

Fisheries and Environmental Sciences
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick E0G 2X0

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ABSTRACT

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During the past few years toxic dinoflagellate blooms have caused fish kills in the Bay of Fundy. Historically these annual blooms have had substantial impact on fisheries resources and public health in Canada because of toxin accumulation in shellfish. We are now learning that the blooms cause problems for finfish as well. Recognition of this comes during a period of intensification of the toxic blooms in the Bay of Fundy. Implications of toxic blooms for finfish extend to the St. Lawrence River Estuary, to the coastal waters of British Columbia, and to many other parts of the world.

This report attempts to assess the scope of the impact of toxic blooms on Canadian finfish resources. The available information is summarized, and additional concerns and gaps in our knowledge are discussed. It is concluded that it is still too early to be able to assess the total impact of the toxic blooms on finfish resources with any degree of accuracy; but the earmarks are present to indicate that toxin-caused fish kills are recurrent events, that a variety of fishes may be affected including adult and larval stages, and consequently that these toxic blooms may well have substantial impact on finfish. The effect of toxic blooms on fish larvae is considered to be the most potentially significant aspect for finfish populations. A knowledge of these effects on larvae is sorely needed, along with a better understanding of the dynamics of toxic blooms and red tides, and of mechanisms of toxin transfer to fish.

Key words: Toxic dinoflagellate blooms, red tide, *Gonyaulax*, fish kills, finfish, Canada

RÉSUMÉ

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Au cours des quelques dernières années, des floraisons toxiques de dinoflagellés ont causé des mortalités massives de poissons dans la baie de Fundy. Par suite de l'accumulation de toxines dans les mollusques, ces floraisons annuelles ont eu dans le passé une forte répercussion sur les ressources halieutiques et la santé publique. On découvre maintenant que les floraisons posent des problèmes également avec les poissons. C'est au moment où les floraisons toxiques se font plus intenses dans la baie de Fundy que l'on reconnaît ce phénomène. Ses implications sur les poissons s'étendent à l'estuaire du Saint-Laurent, aux eaux côtières de la Colombie-Britannique et à plusieurs autres régions du monde.

Nous tentons ici d'évaluer l'ampleur de l'impact des floraisons toxiques sur les ressources ichtyologiques canadiennes. Nous résumons l'information disponible et analysons les problèmes qui peuvent surgir ainsi que les lacunes dans nos connaissances. Nous en venons à la conclusion qu'il est encore trop tôt pour évaluer, avec un degré de précision quelconque, l'impact total des floraisons toxiques sur les poissons; mais on a des indications que les mortalités de poissons causées par les toxines sont des phénomènes périodiques, qu'une variété de poissons, y compris larves et adultes, peuvent être affectés, et que par conséquent ces floraisons toxiques peuvent avoir un impact appréciable sur les poissons. Pour les populations de poissons, nous sommes d'avis que l'impact sur les larves est surtout important. Il y a urgent besoin de connaître les effets sur ces dernières. Il nous faut aussi mieux comprendre la dynamique des floraisons toxiques et des eaux rouges, ainsi que les mécanismes de transfert des toxines aux poissons.

INTRODUCTION

Toxic dinoflagellate blooms are annual events in the Bay of Fundy, in the St. Lawrence River Estuary, along the coast of British Columbia, and in many other coastal areas throughout the world. The culprits in Canada belong to the genus Gonyaulax. East Coast blooms are caused by G. excavata, formerly known as G. tamarensis. West Coast blooms are caused by either G. catenella or G. acatenella.

The impact of the annual Gonyaulax blooms on the utilization of shellfish resources in Canada has been recognized for many years (Prakash et al. 1971; Quayle 1969; White 1982). Filter-feeding shellfish, such as clams and mussels, accumulate the poisons from the dinoflagellates when feeding on them, leading to the danger of "paralytic shellfish poisoning" or PSP, a potentially fatal form of food poisoning for humans and other vertebrates. Contaminated shellfish areas, or sometimes even entire coastlines, must be closed to the harvesting of shellfish for weeks, months or, in some cases, permanently. These natural toxicological events cost Canada millions of dollars annually from the loss of potential shellfish resources, from unemployment of fishermen, and from expenditures required for shellfish surveillance.

Blooms and red tides of other toxic dinoflagellates have been associated with fish kills in some areas of the world for many years. Until 1976 it was thought that Gonyaulax blooms impacted only shellfish resources. Finfish were thought to be relatively insensitive to its toxins. Furthermore, aside from ingestion of contaminated shellfish, no mechanism was recognized whereby finfish could acquire the poisons. However, as a result of studies of herring kills in the Bay of Fundy in 1976 and 1979, and of related studies, the picture is now clearly emerging that toxic Gonyaulax blooms can, and do, have impact on finfish and on finfish resources.

The purpose of this report is to assess the scope of the impact of Gonyaulax blooms on Canadian finfish resources. The assessment will be based upon the information currently available and, by necessity, upon conjecture. The papers cited in the references represent nearly all that is known about G. excavata and its toxins vis à vis finfish, not only in Canada, but worldwide as well. Although the individual papers taken as a whole represent an assessment of sorts, this report is meant to serve as a single focal point for present thoughts on the matter. A more accurate assessment of the significance of Gonyaulax blooms to finfish resources must await further study, particularly on effects of Gonyaulax on fish larvae, which at this point is seen to be the most potentially significant aspect for fish populations.

SUMMARY OF RECENT STUDIES

Some of the published material on Gonyaulax toxins and their relation to finfish has been summarized previously (White 1979b, 1980 b,c). Only the salient features of these studies will be discussed here, along with new results.

The first indication that G. excavata toxins have implications for marine finfish came in 1976. In July of that year an extensive kill of adult herring occurred in the Bay of Fundy off Grand Manan Island during the annual Gonyaulax bloom (White 1977). Analysis of stomach contents showed that the dead herring contained G. excavata toxins, partly digested pteropods, and chromatophore-like bodies which were probably remnants of Gonyaulax cells ingested by the pteropods. Subsequent experiments showed that the amount of toxins found in the herring stomachs (21 µg/fish) was sufficient to kill herring rapidly after oral administration, with symptoms including loss of equilibrium and progressive paralysis, which were the same as symptoms observed by fishermen during the kill (White 1977). The probable course of events was concluded to be that Gonyaulax was grazed upon by pteropods, which accumulated the dinoflagellate toxins and passed them on to herring predators, causing the kill.

During the 1977 and 1978 Gonyaulax blooms, toxin assays of the plankton community were conducted on a regular basis (White 1979a). This work demonstrated that Gonyaulax toxins can be accumulated in zooplankton communities dominated either by tintinnids, cladocerans, or copepods. The timing of the rise and fall in toxin content of zooplankters caught with a 64, 243, or 571 µm mesh net was fairly similar for each size fraction, and roughly paralleled the number of Gonyaulax cells in the water. Toxin content maxima were 91, 59, and 8 µg toxins/g wet plankton for the respective size fractions. The significance of this work was the finding that Gonyaulax toxins can be accumulated by a variety of zooplankters, not just by pteropods. This meant the toxins could, potentially, be transmitted to planktivorous fishes via many different planktonic routes involving herbivorous zooplankton. Furthermore, the results suggested that there was some degree of toxin retention by zooplankton for at least several weeks beyond the time at which no Gonyaulax cells remained in the water.

During the spring of 1979 the accumulation of Gonyaulax toxins by herbivorous zooplankton was confirmed in laboratory experiments (White 1981a). Freshly collected zooplankters were fed cultures of G. excavata and the time course of toxin uptake and excretion by the animals was determined. Gonyaulax cells were rapidly ingested by the copepod Acartia clausii and by barnacle nauplii, and the animals rapidly accumulated Gonyaulax toxins, with no apparent effects. Toxin content of the animals reached maximum values just 6 h after the initiation of feeding on Gonyaulax. In all experiments maximum toxin contents were comparable on a unit weight basis to those measured during the previous years in natural zooplankton samples. Equally important was the finding that toxins were retained at high levels in the test animals for at least several days beyond the time at which particulate matter was no longer visible in their intestines, indicating some degree of toxin retention or storage.

In 1979 fish kill events occurred in the Bay of Fundy which corroborated the view that herbivorous zooplankton in general can acquire Gonyaulax toxins and pass them on to finfish with disastrous results (White 1980a). During the Gonyaulax bloom in July 1979, the toxins again caused herring kills. In these instances the primary agent of toxin transfer was the cladoceran Evadne nordmanni, not pteropods as in 1976. Examination of stomach contents revealed only G. excavata toxins, E. nordmanni in various stages of digestion, and the same yellowish chromatophores as seen in stomach contents in 1976.

The 1979 kill coincided with the peak of the Gonyaulax bloom when E. nordmanni overwhelmingly dominated the zooplankton community. Furthermore, Gonyaulax toxins were measured in E. nordmanni samples - 18 μg toxins/g wet animals. These events demonstrate that herring kills caused by Gonyaulax toxins are a recurrent phenomenon.

A study of the sensitivity of several marine fishes to Gonyaulax toxins has recently been completed which suggests that kills of fishes other than herring are possible during Gonyaulax blooms. Toxins were extracted from mass cultures of G. excavata and administered either orally or intraperitoneally in herring, pollock, flounder, salmon, and cod (White 1981b). The symptoms and the dose responses are very nearly the same among these fishes. Symptoms include loss of equilibrium within 5-15 min, followed by shallow arrhythmic breathing. Death ensues generally within 20-60 min of toxin administration. Oral LD50 values are 400-755 μg toxins/kg body weight. Intraperitoneal LD50 values are very low, 4-12 μg toxins/kg body weight, which are similar to those for warm-blooded vertebrates. Fish receiving lethal oral doses showed undetectable levels of toxins in their muscle tissue, which is consistent with the finding that only very low levels of toxins are required to kill fish via the intraperitoneal route. These results suggest that kills of a variety of marine fishes from Gonyaulax toxins are possible if sufficient amounts of the poisons have been accumulated by their food organisms.

RECURRENCE OF HERRING KILLS

Gonyaulax toxins caused kills of adult herring in the Bay of Fundy during the summer blooms in 1976 and 1979 (White 1977, 1980a). The mechanism of toxin transfer was the same in these instances. Toxins were transmitted from Gonyaulax to herbivorous zooplankton to herring. The zooplankton vectors were different however - pteropods in 1976 and cladocerans in 1979. Laboratory and field work indicate that a variety of planktonic herbivores can act as toxin vectors (White 1981a). Therefore, since herring are obligate planktivores, herring kills should recur whenever a large number of Gonyaulax, herbivorous zooplankters, and herring overlap temporally and spatially (White 1980a, 1981a).

It is impossible to determine with certainty if the herring kills are new events in the Bay of Fundy, or if they have happened in the past and either have not been observed or not reported. It seems somewhat unlikely that a major kill of adult fish would have been unnoticed in recent history. However, it is not unlikely that such an occurrence would be unrecorded. Kills of fish larvae would certainly be unobserved.

On the other hand, if the kills are new events they may foreshadow more dramatic things to come. Shellfish toxicity records for the Bay of Fundy for the past 39 yr support this possibility. Within the past 8 yr or so there has been a definite increase in shellfish toxin levels, signifying an intensification of Gonyaulax blooms (White 1982). The 1976 and 1979 herring kills occurred during years of massive Gonyaulax blooms, as reflected by shellfish toxicity peaks much higher than in any other year since 1961. The trend of increasing severity of blooms continued in 1980. In fact, a Gonyaulax-caused red tide was recorded for the first time in the Bay of Fundy in 1980 (White, unpublished). In one location Gonyaulax numbers reached 18 million cells per liter! However, herring kills were not reported during 1980, which may have been related to the paucity of zooplankters observed during the Gonyaulax bloom. The worsening of the Gonyaulax bloom situation in the Bay of Fundy is in keeping with the same disturbing trend worldwide, i.e. an increase in the frequency, severity, and distribution of red tide events.

KILLS OF OTHER FISHES

Experimental work has shown that marine fishes in general are equally sensitive to G. excavata toxins (White 1981b). One would expect, therefore, that kills will result whenever fishes consume food items containing sufficient toxin loads. Although we do not know the complete fate of Gonyaulax toxins in the marine food web, we do know for certain that the toxins can be accumulated by zooplankton, by filter-feeding shellfish, and secondarily by some carnivorous shellfish. Depending upon their feeding habits, fishes may acquire lethal doses of toxins from the dinoflagellates themselves or from a variety of secondary accumulators. We do not know if the toxins in solution in seawater during the blooms (the toxins are water soluble) affect fish as do the toxins from the Gulf of Mexico red-tide dinoflagellate.

Gonyaulax excavata toxins have, in fact, been associated with kills of fishes other than herring. Adams et al. (1968) suggested that a sand lance (Ammodytes sp.) kill off the United Kingdom in 1968 was caused by G. excavata (then called G. tamarensis) toxins which were probably transferred through the zooplankton community. Another sand lance kill occurred off Cape Cod, Massachusetts, in 1978 during a Gonyaulax bloom, and toxins were measured in the fish guts (I. Nisbet, pers. comm.). Bluefish (Pomatomus saltatrix) may have been involved in this kill as well. Sand lance, like herring, feed exclusively on small zooplankton and must have acquired the toxins in this manner. The same kind of scenario might well involve other planktivorous fishes, such as alewife, shad, smelt, mackerel, etc., simply depending upon which fishes are in the wrong place at the wrong time.

In 1979 a menhaden kill occurred off the coast of Maine during a G. excavata red tide and toxins were measured in the guts (J. Hurst, pers. comm.). Menhaden possess fine pharyngeal sieves which enable them to filter phytoplankton. Dinoflagellates and diatoms constitute a large part of their diet. It is likely then that these fish acquired the toxins directly from Gonyaulax. Other phytoplanktivorous fishes would probably experience the same problems in areas of high Gonyaulax concentrations.

It is not known if groundfish kills result when toxic shellfish are eaten. However, sea scallops in the Bay of Fundy often contain extremely high levels of G. excavata toxins. Furthermore, these high levels do not necessarily occur during or shortly after the summer Gonyaulax bloom, but can occur during the winter. It is strongly suspected that scallops ingest G. excavata cysts which are deposited in abundance on sediments after the bloom and which remain there throughout the fall and winter.

Although not a major item in the diets of groundfish such as cod, halibut, haddock, etc., scallops are taken fairly regularly as shown by stomach content analyses, so it is possible that there are detrimental effects of the toxins on groundfish via this route. In addition to scallops many other bivalve and gastropod molluscs serve as potential toxin vectors to groundfish.

KILLS IN OTHER AREAS

There is little reason to consider that fish kills caused by Gonyaulax toxins can occur only in the Bay of Fundy. The same dinoflagellate species as in the Bay of Fundy blooms regularly in the St. Lawrence River Estuary. Very closely related species, G. catenella and G. acatenella, bloom annually, often reaching red tide proportions, all along the coast of British Columbia. The toxins of these organisms are very similar to those of G. excavata. Toxic Gonyaulax blooms also appear regularly in New England, the United Kingdom, Norway, and Japan. Recently they have also been reported in Spain and Venezuela. I suspect that Gonyaulax toxins impinge upon finfish populations in all of these locations.

IMPACT OF TOXINS IN FISH PRODUCTS

Because of the danger of PSP, Gonyaulax blooms have a tremendous negative impact on the economics of the shellfish industry on both Canadian coasts. The impact involves nearly every facet of the industry - harvesting, surveillance, importing/exporting, marketing, publicity, and consumer purchasing. PSP and red tides receive "bad press" in the sense that consumers are not made altogether sure of which seafood products to be cautious, and consequently many are reluctant to buy any seafood products until the red tide/PSP storm subsides.

The question arises whether Gonyaulax toxins can reach sufficient levels in finfish products to impact fisheries by causing problems in terms of fish as food. The answer to this is probably no. The crux of the matter here is that whereas shellfish are insensitive to the toxins and therefore can accumulate large amounts with little effect, finfish, like other vertebrates, are very sensitive to the toxins and so are not able to store them to any degree because even low doses cause death. Experimental results show that the LD50 values for the toxins administered intraperitoneally to herring, pollock, flounder, salmon, and cod are extremely low - 4-12 μg toxins/kg body weight, which is the same range as for warm-blooded animals (White 1981b). Consequently, toxins are undetectable in meat samples, even after fish have been fed very high doses (White 1981b), because extremely low systemic levels of toxins cause the fish to die. Toxins were also undetectable in meat samples of herring from the 1976 and 1979 kills, with the exception of two samples from decayed fish which showed marginally detectable levels, probably resulting from leakage of toxins from the guts (White 1981a). Higher, oral LD values for fish (400-750 μg toxins/kg body weight) mean that measurable amounts can be expected in fish guts when fish receive lethal doses, as shown in the laboratory (White 1981b) and in natural kills (White 1977, 1980a; I. Nisbet, J. Hurst, pers. comm.). However these amounts are relatively low, compared to shellfish, for instance, and the toxins are confined to the guts, so it is quite unlikely that any human health problems would result via this route.

In summary, there would appear to be little likelihood that Gonyaulax blooms impact finfish resources from the point of view of the suitability of fish as food. The problem of consumer wariness and avoidance of seafood products in general, including fish products, as a result of Gonyaulax blooms, red tides, and PSP is real, however, and difficult to quantify. Public education is the solution here. Wide distribution of materials such as the recent DFO Red Tide Fact Sheet (White 1980d) is helpful.

EFFECTS OF GONYAULAX BLOOMS ON LARVAL FISH

Discussion in this section is obliged to be mainly conjectural since next to nothing is known about the effects of Gonyaulax on fish larvae. In terms of population dynamics and finfish resources, however, the most significant aspect of the impact of Gonyaulax blooms on finfish may well be the effects on larval and juvenile stages. It is an accepted tenet among fisheries scientists that events which occur during the larval stages are the major determinants of recruitment, and hence, of year-class strength. Accordingly, Gonyaulax blooms may influence the population size of finfish whose larvae overlap the blooms in time and space. At this stage there is little reason to doubt that marine fish larvae are sensitive to Gonyaulax toxins. On the contrary, general biological principles would support the view that larvae may be even more sensitive than adults.

Marine fish larvae are obligate planktivores and thus are liable to acquire Gonyaulax toxins from the plankton community during blooms. Toxins can be acquired directly from Gonyaulax or secondarily from zooplankton. For the most part the details of the feeding capabilities and preferences of marine fish larvae are not known. Herring larvae, which have large mouths relative to other larvae, may be exclusively zooplanktivorous. However, other larvae may take Gonyaulax (and other phytoplankton) directly, especially during first-feeding stages, as well as feeding on microzooplankton. Regardless of the specific food items chosen, any fish larvae in the midst of a Gonyaulax bloom would likely become exposed to the toxins through the feeding process.

Results of an experiment with herring larvae add to the plausibility of the idea that larvae are sensitive to the toxins and that kills of larvae can occur during Gonyaulax blooms (White, unpublished). During the fall of 1979 we reared herring larvae from eggs until near metamorphosis. When larvae were large enough (at least 16 mm in length) to eat small copepods, some were fed copepods containing toxins and some were fed clean copepods. The copepods (nearly exclusively Acartia clausii) had been contaminated with toxins by allowing them to feed overnight on G. excavata cultures.

Both groups of larvae fed well on the copepods. After just 4 d, however, there was a 20% increase in mortality in the group of larvae fed toxin-containing copepods relative to the control group. This result was obtained when the toxin level in the copepods (approximately 30 μg toxins/g animals) was only about one-half of that measured in wild zooplankton collected during the 1977 and 1978 Gonyaulax blooms in the Bay of Fundy (White 1979a and unpublished). During the experiment as many as 10 or 12 copepods were commonly observed in the guts of larvae. Assuming that fish larvae have an oral LD50 value similar to adults (650 μg toxins/kg body weight), calculations show that in this experiment as few as 15-20 copepods would have constituted a lethal dose for a herring larva, or only 7-10 copepods under the more toxic field conditions in 1977 and 1978.

These results provide a tantalizing piece of preliminary evidence that there may be substantial detrimental effects of Gonyaulax blooms on larval fishes. Although the dynamics of stock recruitment are not known well enough to be able to assess the significance of, say, a 20% increase in mortality of herring larvae to subsequent year-class strength, effects of this magnitude might be expected to have considerable repercussions. In addition, Gonyaulax effects may be cumulative. It may be that Gonyaulax blooms impact populations of fish larvae every year, to a greater or lesser extent, and may have done so through evolutionary history.

What species of fishes might be affected in this manner? In the Bay of Fundy alone a whole variety of larvae could potentially be affected. The annual Gonyaulax bloom occurs anytime between May and October, although generally in June, July, or August. The bloom usually lasts from 4-8 wk. There are many commercially important groundfish species which spawn in the spring and whose larvae occur in the Bay of Fundy in late spring and early summer, including cod, haddock, halibut, redfish, winter flounder, plaice, etc. In the summer silver hake and mackerel larvae are most common, although groundfish larvae are found occasionally as well. Herring larvae are, of course, the major ichthyoplankters in the later summer and early fall. There are a number of other larvae present during the May-October period which represent species not directly important in commercial terms, but which are important indirectly because of their role as food for commercial fishes. This group includes the sea snail, radiated shanny, lumpfish, four-bearded rockling, sand lance, etc.

In sum, what we have learned about Gonyaulax toxins in plankton and about the sensitivities of adult marine fishes to the toxins would suggest that Gonyaulax blooms can kill larval fishes as well through food web transfer. If so, then the blooms may have an important bearing on population dynamics of fishes in affected areas. It is quite possible that these effects on larval fishes represent the major impact of the toxic blooms on finfish populations. It may be that if larvae are, for some reason, insensitive to the toxins then Gonyaulax blooms have a beneficial effect on larval fish populations because they represent such large pulses of carbon into the plankton community during a period when phytoplankton productivity is otherwise low. Clearly there is a need for continuing investigation of the role of toxic dinoflagellate blooms in larval fish dynamics.

CONCLUSION

The substantive information concerning G. excavata toxins and finfish can be summarized into three major points. First, the toxins have caused recurrent kills of adult herring in the Bay of Fundy and have been associated with sand lance kills in other areas. Second, sources of toxins available to finfish are the dinoflagellates themselves, herbivorous zooplankton, shellfish, and probably other components of the food web. And third, marine fishes in general are sensitive to the toxins.

This information is not nearly sufficient for assessing the full impact of the blooms on finfish resources with any degree of accuracy. We need to know a good deal more about the fate of the toxins in the food web and the degree of retention of the toxins in different organisms. In order to have projective or predictive capability, we need to know more about the underlying causes, triggering factors, and dynamics of the blooms themselves. Most important, however, we need to know about the effects of the toxic dinoflagellates and toxin-containing zooplankton on fish larvae.

Although it is premature to assess accurately the impact of the blooms on finfish, we can make some rough guesses as to the scope of the impact. Because the toxins accumulate in zooplankton, in molluscan shellfish, and probably in other animals too, and because marine fishes are in general sensitive to the toxins, then the scope of the impact of the toxic blooms is likely to include all fish larvae, all juvenile and adult planktivorous fishes, and some demersal fishes, as long as they overlap the blooms temporally and spatially. Since shellfish can retain the toxins for extended periods, and can very likely acquire additional amounts from the toxic, overwintering, benthic cysts of Gonyaulax (White 1982) then demersal fish may be affected year-round.

In terms of fish populations, the impact of toxin-caused kills of adult fish is probably transitory and of moderate significance, at most, to fish stocks in a region. However kills of adult fish may have significant bearing on fish catches, or landings, in bloom areas because of outright depletions of local populations or because of subsequent avoidance of the kill sites by other fishes. For example, the extensive herring kill off the east coast of Grand Manan in mid-July, 1976, was associated with a substantial decline in herring catches in that area throughout the remainder of the season.

On the other hand, the impact of toxic blooms on larval fishes may have far-reaching significance at the population level, because of effects on recruitment success, and consequently on year-class strengths and sizes of fish stocks. One must also consider that since Gonyaulax blooms occur annually, the effects on fish are recurrent, regardless of whether operating on larvae or adults or both, so that the total impact on fish populations is the resultant of the effects of exposure to toxic blooms for a number of years.

The recent realization of the impingement of Gonyaulax blooms on finfish resources comes during a period of intensification of the annual blooms in the Bay of Fundy (White 1982). Further, in terms of bloom intensification, the Bay of Fundy does not appear unusual. During the past few years an increase in the intensity and distribution of toxic dinoflagellate blooms and red tides is apparent nearly throughout the world (see LoCicero 1975; Taylor and Seliger 1979). This trend has disturbing implications for Canadian fisheries resources - both finfish and shellfish - in the Bay of Fundy, in the Gulf of St. Lawrence, and along the coast of British Columbia.

This essay raises many more questions than it answers. Its primary purpose is to draw attention to the existence of a newly recognized area of concern to Canadian fisheries and to make an initial estimate of the scope of the potential impact on finfish and finfish resources. Assessment, prediction, and amelioration of the consequences of these toxic blooms to fisheries resources depend upon a better fundamental understanding of the blooms, toxin transfer through the food web, and effects on finfish, particularly on larval and juvenile stages.

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REFERENCES

Adams, J. A., D. D. Seaton, J. B. Buchanan, and M. R. Longbottom. 1968. Biological observations associated with the toxic phytoplankton bloom off the east coast. Nature 220: 24-25.

LoCicero, V. R. [Ed.]. 1975. Proceedings of the first international conference on toxic dinoflagellate blooms. Mass. Sci. Technol. Found., Wakefield, Mass., 541 p.

Prakash, A., J. C. Medcof, and A. D. Tennant. 1971. Paralytic shellfish poisoning in eastern Canada. Bull. Fish. Res. Board Can. 177: 87 p.

Quayle, D. B. 1969. Paralytic shellfish poisoning in British Columbia. Bull. Fish. Res. Board Can. 168: 68 p.

Taylor, D. L., and H. H. Seliger [Eds.]. 1979. Toxic dinoflagellate blooms. Proceedings of the second international conference on toxic dinoflagellate blooms. Developments in marine biology, Vol. 1. Elsevier/North-Holland, New York, N.Y., 505 p.

White, A. W. 1977. Dinoflagellate toxins as probable cause of an Atlantic herring (Clupea harengus harengus) kill, and pteropods as apparent vector. J. Fish. Res. Board Can. 34: 2421-2424.

White, A. W. 1979a. Dinoflagellate toxins in phytoplankton and zooplankton fractions during a bloom of Gonyaulax excavata, p. 381-384. In D. L. Taylor and H. H. Seliger (eds.) Toxic Dinoflagellate Blooms. Developments in Marine Biology, Vol. 1. Elsevier, North Holland, N.Y.

White, A. W. 1979b. Relation of toxic dinoflagellate blooms to finfish in the southern Bay of Fundy and northwestern Gulf of St. Lawrence: a summary of recent studies and a rationale for investigations on fish larvae. Canadian Atlantic Fisheries Scientific Advisory Committee Res. Doc. 79/2, 10 p.

White, A. W. 1980a. Recurrence of kills of Atlantic herring (Clupea harengus harengus) caused by dinoflagellate toxins transferred through herbivorous zooplankton. Can. J. Fish. Aquat. Sci. 37: 2262-2265.

White, A. W. 1980b. Fate and consequences of dinoflagellate toxins in marine food chains. ICES C.M. 1980/L:15, 9 p.

White, A. W. 1980c. Red tides and plankton blooms, their relationship to eutrophication, and a summary of the Canadian situation. Rept. submitted to ICES Advisory Committee on Marine Pollution in March, 1980, 11 p.

White, A. W. 1980d. Red tides. Underwater World Fact Sheet UW80/001E. Comm. Branch., Dept. Fish. Oceans, Ottawa, 8 p.

White, A. W. 1981a. Marine zooplankton can accumulate and retain dinoflagellate toxins and cause fish kills. Limnol. Oceanogr. 26: 103-109.

White, A. W. 1981b. Sensitivity of marine fishes to toxins from the red-tide dinoflagellate Gonyaulax excavata and implications for fish kills. Mar. Biol. 65: 255-260.

White, A. W. 1982. Intensification of Gonyaulax blooms and shellfish toxicity in the Bay of Fundy. Can. Tech. Rep. Fish. Aquat. Sci. 1064: 12 p.