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INTENSIFICATION OF *GONYAULAX* BLOOMS AND SHELLFISH TOXICITY IN THE BAY OF FUNDY

by

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ABSTRACT

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Shellfish toxicity records for the Bay of Fundy show that during the past 8 yr or so toxic *Gonyaulax* blooms and shellfish toxicity have been more intense than at any time in the preceding 30-yr period. In addition to dangerously high shellfish toxicity levels during the summer, there has been a recent trend of persistence of toxicity throughout the rest of the year, probably caused by prolonged depuration of high summer toxin loads and by recontamination of shellfish upon ingestion of overwintering *Gonyaulax* cysts. Recent year-round closures of major shellfish areas are unprecedented in the 39-yr history of the shellfish toxicity monitoring program. Possible courses of action which may help the shellfish industry cope if present trends continue include development of detoxification methods, production of canned shellfish, and exploration of the possibility of slightly relaxing the present shellfish toxicity limit during non-bloom periods.

Key words: *Gonyaulax excavata*, toxic dinoflagellate blooms, shellfish toxicity, PSP, red tide, Bay of Fundy

RÉSUMÉ

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Les données sur la toxicité des mollusques dans la baie de Fundy indiquent qu'au cours des quelque 8 dernières années, les floraisons toxiques de *Goniaulax* et la toxicité des mollusques ont été plus intenses qu'en aucun temps depuis 30 ans. En plus de niveaux de toxicité dangereusement élevés chez les mollusques en été, cette toxicité tendance à persister tout au long de l'année. Ceci est probablement dû à une dépuration prolongée de fortes charges estivales de toxines et à une recontamination des mollusques par ingestion de kystes de *Goniaulax* hibernants. Depuis 39 ans que l'on surveille la toxicité des mollusques, c'est seulement en ces dernières années qu'on a dû fermer à l'année longue les principales zones de pêche des mollusques. Parmi le mesures susceptibles d'aider l'industrie à faire face à la situation si cette tendance persiste, mentionnons: la mise au point de méthodes de détoxification, la production de mollusques en conserve et la possibilité de relever légèrement la limite actuelle de toxicité des mollusques pendant les période de non-floraison.

INTRODUCTION

Blooms of the toxic marine dinoflagellate Gonyaulax excavata (formerly G. tamarensis) have been annual events for many years in the Bay of Fundy and in the St. Lawrence River Estuary. During the blooms molluscan shellfish accumulate the dinoflagellate toxins while feeding, posing the danger to humans and other vertebrates of a potentially fatal form of food poisoning called "paralytic shellfish poisoning" or PSP. The reality of the danger of PSP to humans is demonstrated by the fact that since 1880 hundreds of cases of sickness and 26 deaths caused by PSP have been confirmed in eastern Canada (Prakash et al. 1971), the most recent deaths occurring in Quebec in 1974 and 1981 (Turgeon, personal communication). The Gonyaulax blooms are important for the shellfish industry because closures of areas to harvesting are necessary when the shellfish become unsafe for human consumption, and because toxic shellfish have far-reaching impact on shellfish marketing (see Lutz and Incze 1979).

A comprehensive summation of information on PSP and shellfish toxicity in eastern Canada, including details of the PSP control program, was published in 1971 (Prakash et al. 1971). Much of the material in that report is pertinent to the present shellfish toxicity situation. However, since then there has been a pattern of intensification of Gonyaulax blooms and shellfish toxicity in the Bay of Fundy. The magnitude of the shellfish toxicity problem has increased during this period and its complexion has changed from 10 yr ago. Further, the impact of the blooms has amplified to include effects on finfish, as well as shellfish, resources.

The purposes of this report are to document the intensification of Gonyaulax blooms and the increase in shellfish toxicity in the Bay of Fundy, to discuss research results which bear upon the recent extension of shellfish toxicity into non-bloom periods, to present a brief overview of the current situation, and to suggest some courses of action. This report addresses the problem of Gonyaulax and shellfish toxicity only. The newly recognized implications of Gonyaulax blooms for finfish resources are discussed in a separate report (White 1982).

GEOGRAPHICAL DISTRIBUTION

The areas in eastern Canada in which Gonyaulax and toxic shellfish occur are shown in Fig. 1. The geographic pattern in eastern Canada has not changed appreciably in the last 10 yr from that depicted by Prakash et al. (1971). In the Bay of Fundy toxic shellfish occur along the coast of Nova Scotia from the Yarmouth area northeastward to at least the Margaretsville area. Along the New Brunswick coast toxic shellfish occur from Passamaquoddy Bay and the Quoddy region to the St. Martins area, northeast of Saint John. Toxic shellfish are rare towards the head of the Bay of Fundy (Prakash et al. 1971).

During the past 10 yr there has been a change in the distribution of Gonyaulax and toxic shellfish along the northeast coast of the United States. Until 1971 toxic shellfish were found regularly only as far south as the Cobscook Bay area at the easternmost point of the Maine coast (see Fig. 2 in Prakash et al. 1971). However, since 1972, when

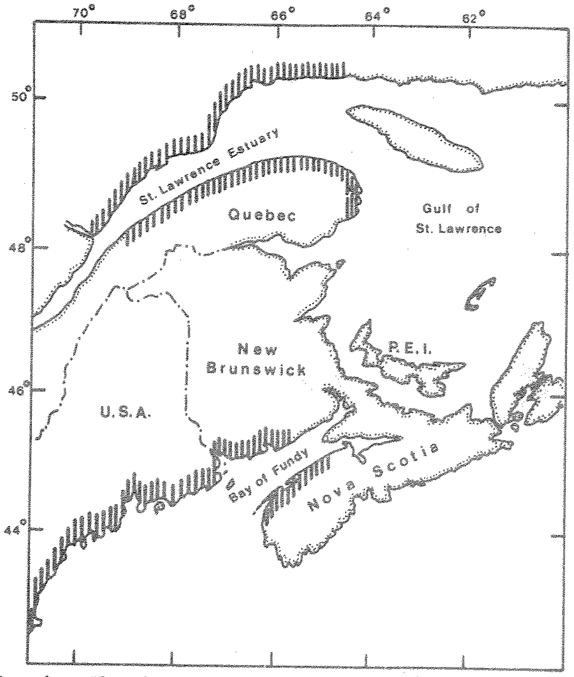

Fig. 1. The distribution of Gonyaulax blooms and shellfish toxicity (hatched areas) in eastern Canada and New England (modified from Prakash et al. 1971).

Gonyaulax cells from the Bay of Fundy area were apparently spread southwestward along the New England coast by the northeasterly winds preceding Hurricane Carrie (Hartwell 1975), Gonyaulax blooms and shellfish toxicity have occurred annually along this coast (Hurst and Yentsch 1981) as far south as Cape Cod.

GENERAL PATTERN OF GONYAULAX BLOOMS AND SHELLFISH TOXICITY UNTIL ABOUT 1974

The temporal pattern and the degree of summertime accumulation of Gonyaulax toxins by shellfish closely parallel the number of Gonyaulax cells in the plankton as demonstrated by studies of the bloom dynamics in 1977, 1978, 1980, and 1981 (White 1979 and unpublished data). Thus the annual patterns of the toxic blooms in the Bay of Fundy over the years can be inferred from the annual shellfish toxicity records compiled by the Fish Inspection Laboratory in Black's Harbour, N.B. These records extend back to 1943.

The locations of four sampling stations in the southwestern Bay of Fundy for which long time-series of shellfish toxicity data are available are shown in Fig. 2. Mean monthly toxicity values at these stations were calculated from the records and are plotted in Fig. 3-8. The data are comparable because the mouse bioassay method (AOAC 1975; Prakash et al. 1971) has been used throughout the years with few technical changes. Until 1958, toxicity was expressed in "mouse units" of toxin. These were changed to "micrograms of saxitoxin equivalent" using the conversion factor of 0.16. It should be noted that Fig. 3 shows toxicity of blue mussels (Mytilus edulis), and Fig. 7 shows toxicity of horse mussels (Modiolus modiolus). The other figures show toxicity of soft-shell clams (Mya arenaria). Mussels generally become more toxic than

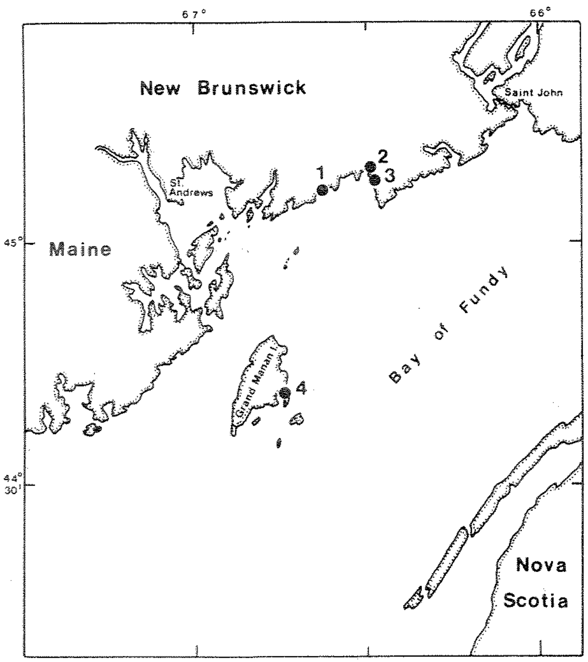

Fig. 2. Locations of the shellfish sampling stations referred to in Fig. 3-8: 1) Crow Harbour, 2) Lepreau Harbour, 3) Lepreau Basin, and 4) Ross Island thoroughfare.

clams (Prakash et al. 1971). This is well demonstrated by comparing mussel toxicity at Lepreau Basin (Fig. 3) with clam toxicity at the same location (Fig. 4).

Inspection of the figures reveals that toxicity trends from year to year generally follow strikingly similar patterns between stations and between organisms, although for any particular year there are obvious differences in the absolute toxicity values between stations. In other words, toxicity events apparent in one set of scores are usually mirrored in the other sets. Thus, on the whole, the southern Bay of Fundy behaves largely as a unit in terms of shellfish toxicity dynamics, as noted by Prakash et al. (1971).

As inferred from the shellfish toxicity data, the annual sequence of Gonyaulax blooms and resulting shellfish toxicity which was characteristic of the Bay of Fundy during the approximately 30-yr period between 1944 and about 1974 was the following: At some time between June and September each year a Gonyaulax bloom developed. The blooms were of varying intensity and duration from year to year, but for most years they were of low to moderate intensity during this period, lasting generally 4 to 8 wk during the summer. On occasion more intense blooms developed, as in 1961.

It is clearly apparent from Fig. 3-8 that toxicity of clams and mussels during this 30-yr period was very largely a summertime problem. The overall pattern was that toxicity increased during the summer from low, residual values to values ranging from slightly to substantially above the safety threshold of 80 μg saxitoxin equivalent per 100 g shellfish tissue. Peak toxicity generally occurred in July or August. After the peak, when Gonyaulax cells started to disappear from the plankton, toxicity values decreased through natural depuration so that by September, generally, they were close to, or below, the safety threshold. An obvious exception to this pattern occurred in 1961, when shellfish toxicity reached very high values at all stations. In this case, toxicity levels at Lepreau Basin did not return to the vicinity of the safety threshold for many months (Fig. 3, 4).

During the 30-yr period, shellfish areas in the Bay of Fundy were often closed to harvesting during the summer months, but were opened during the early fall and remained opened until the following summer. Further, in some years all areas remained open throughout the year. Thus, although the summer closures presented economic problems for the shellfish industry in the Bay of Fundy, diggers and distributors were able to "work around" the closures, using 9 or 10 mo of the year for harvesting.

INTENSIFICATION OF GONYAULAX BLOOMS AND SHELLFISH TOXICITY SINCE ABOUT 1974

Over the past 8 yr or so there has been a pattern of intensification of Gonyaulax blooms in the Bay of Fundy as reflected by the shellfish toxicity values. Elevated shellfish toxicity levels since about 1974 are clearly evident in all of the toxicity charts (Fig. 3-8). Toxicity levels during this period have been much higher than during any similar interval in the preceding 30-yr.

There is other evidence of the intensification of Gonyaulax blooms in recent years. In 1976 and again in 1979 Gonyaulax blooms caused herring kills in the Bay of Fundy, as a result of toxin accumulation in, and transfer through, herbivorous zooplankton (White 1977, 1979, 1980 a,b, 1981 a,b). As far as we know, these are the first instances in which Gonyaulax blooms have caused fish kills in the Bay of Fundy. Also, in August 1980, Gonyaulax-caused red tide was observed in the Bay of Fundy (White, unpublished), again apparently for the first time (Prakash et al. 1971). Cell counts as high as 18 000 000 Gonyaulax cells/L were recorded. The final evidence of bloom intensification, which will be discussed in more detail below, is that shellfish toxicity levels above the safety threshold have occurred during the winter months in recent years (Fig. 3-8). The wintertime toxicity is probably caused, at least in part, by the increased number of toxic, overwintering cysts produced during the enhanced blooms.

During the past few years the seasonal pattern of shellfish toxicity has been modified from what it was in the past. Peak toxicity still occurs in the summer during the Gonyaulax bloom (Fig. 3-8), but there has been a trend of extension of above-threshold toxicity well into non-bloom periods of the year (see especially Fig. 5, 7). In fact, since the early summer of 1980 toxicity levels in all major shellfish areas along the southwest coast of New Brunswick have been above the safety threshold nearly continuously until this report was written (December 1981) - a situation of unprecedented extent since the shellfish toxicity monitoring program was initiated in 1943. Until recently, relatively high wintertime toxicity occurred only occasionally and only at certain locations, as for example at Lepreau Basin in 1961 and 1962 (Fig. 3, 4).

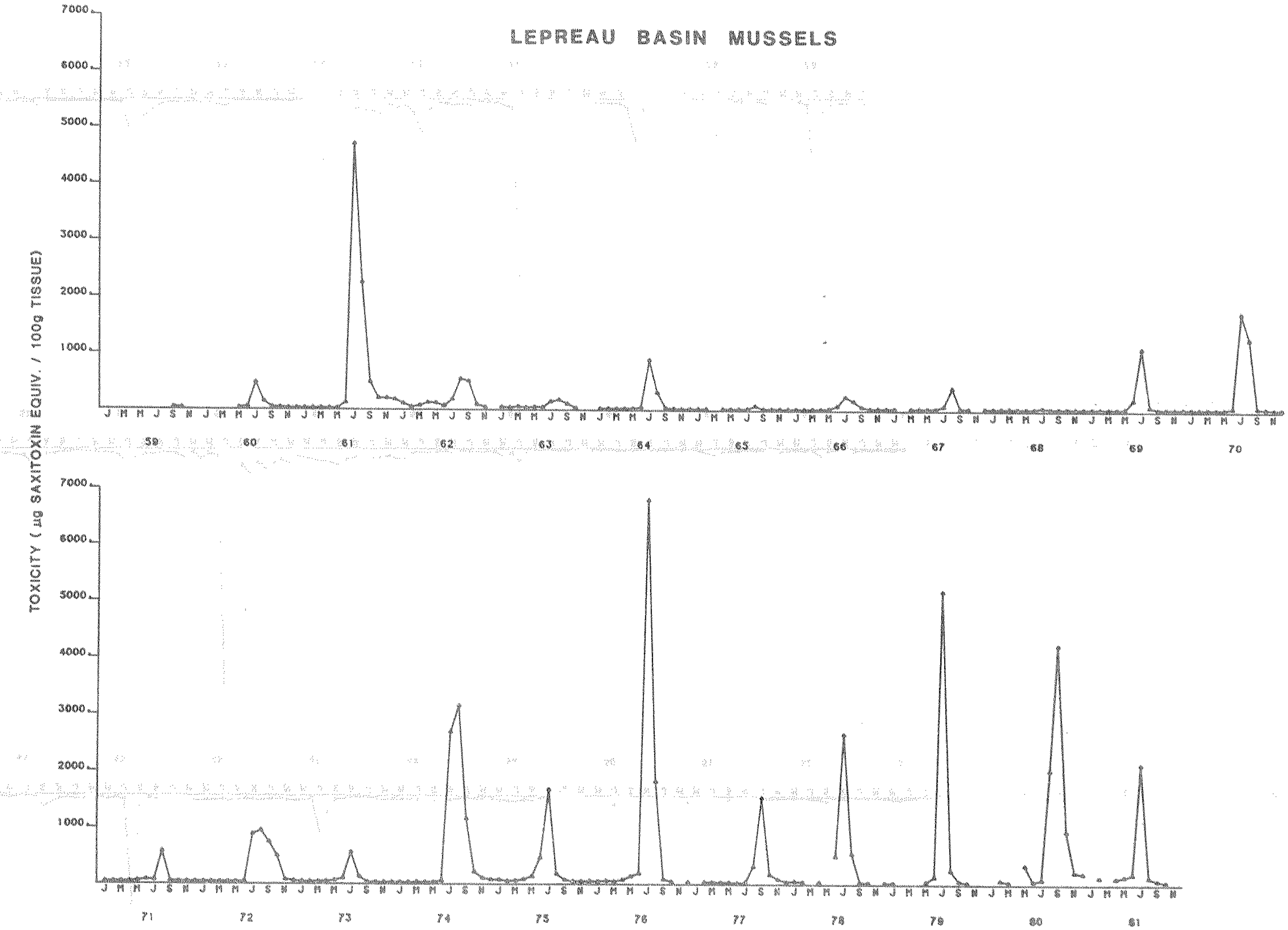

Fig. 3. Mean monthly toxicity of blue mussels (<u>Mytilus edulis</u>) at Lepreau Basin, 1959-81.

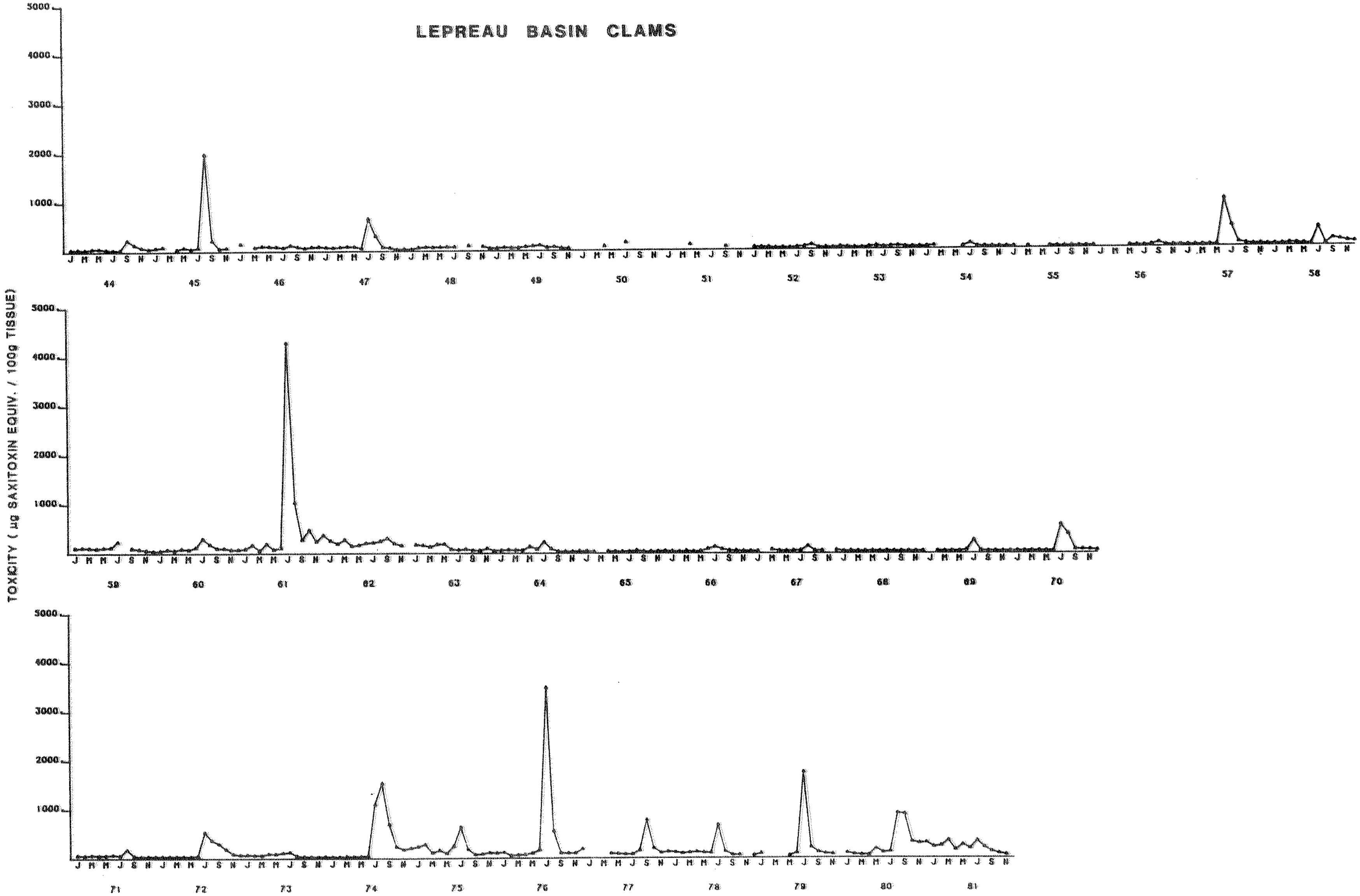

Fig. 4. Mean monthly toxicity of soft-shell clams (Mya arenaria) at Lepreau Basin, 1944-81.

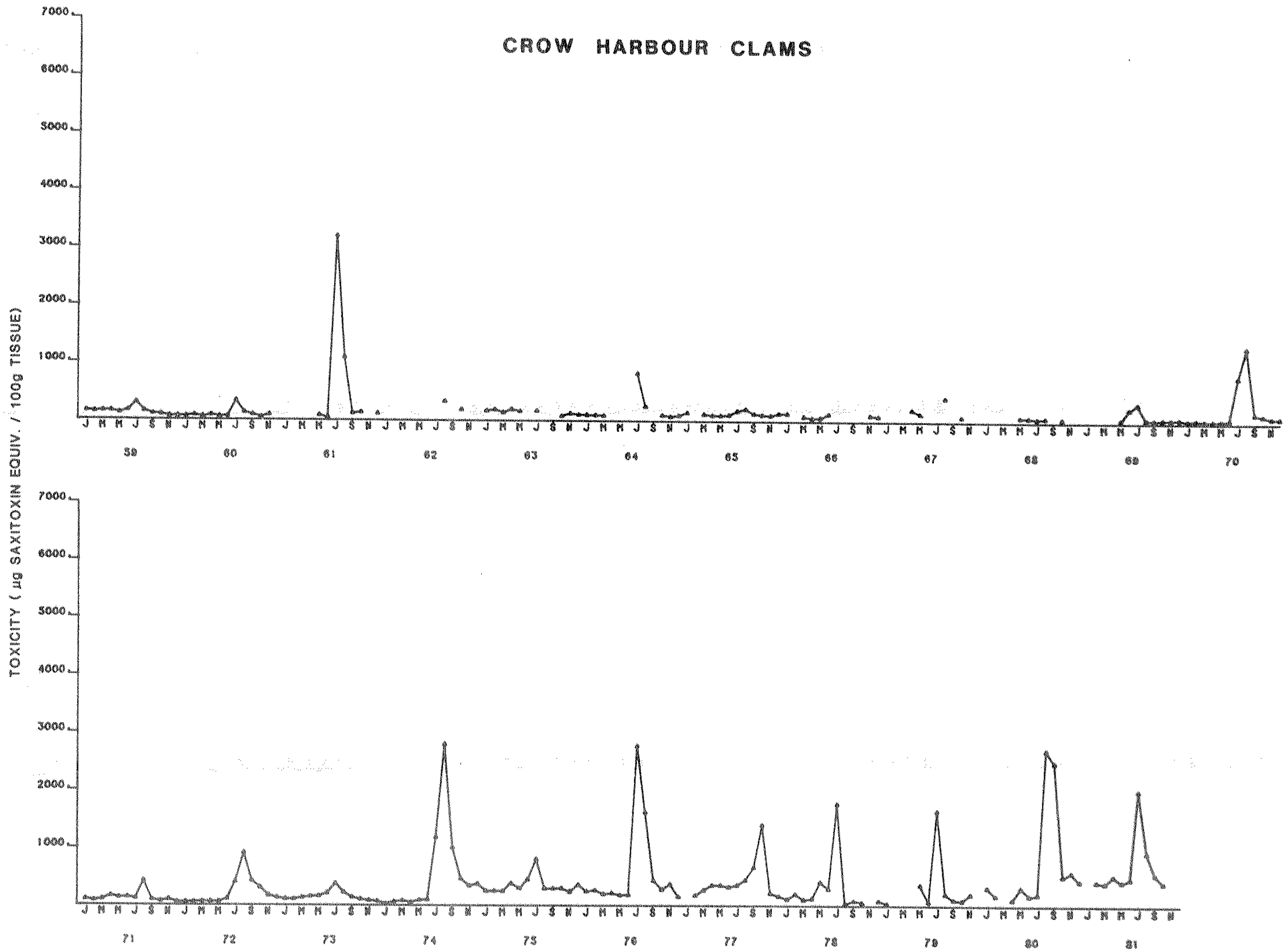

Fig. 5. Mean monthly toxicity of soft-shell clams (Mya arenaria) at Crow Harbour, 1959-81.

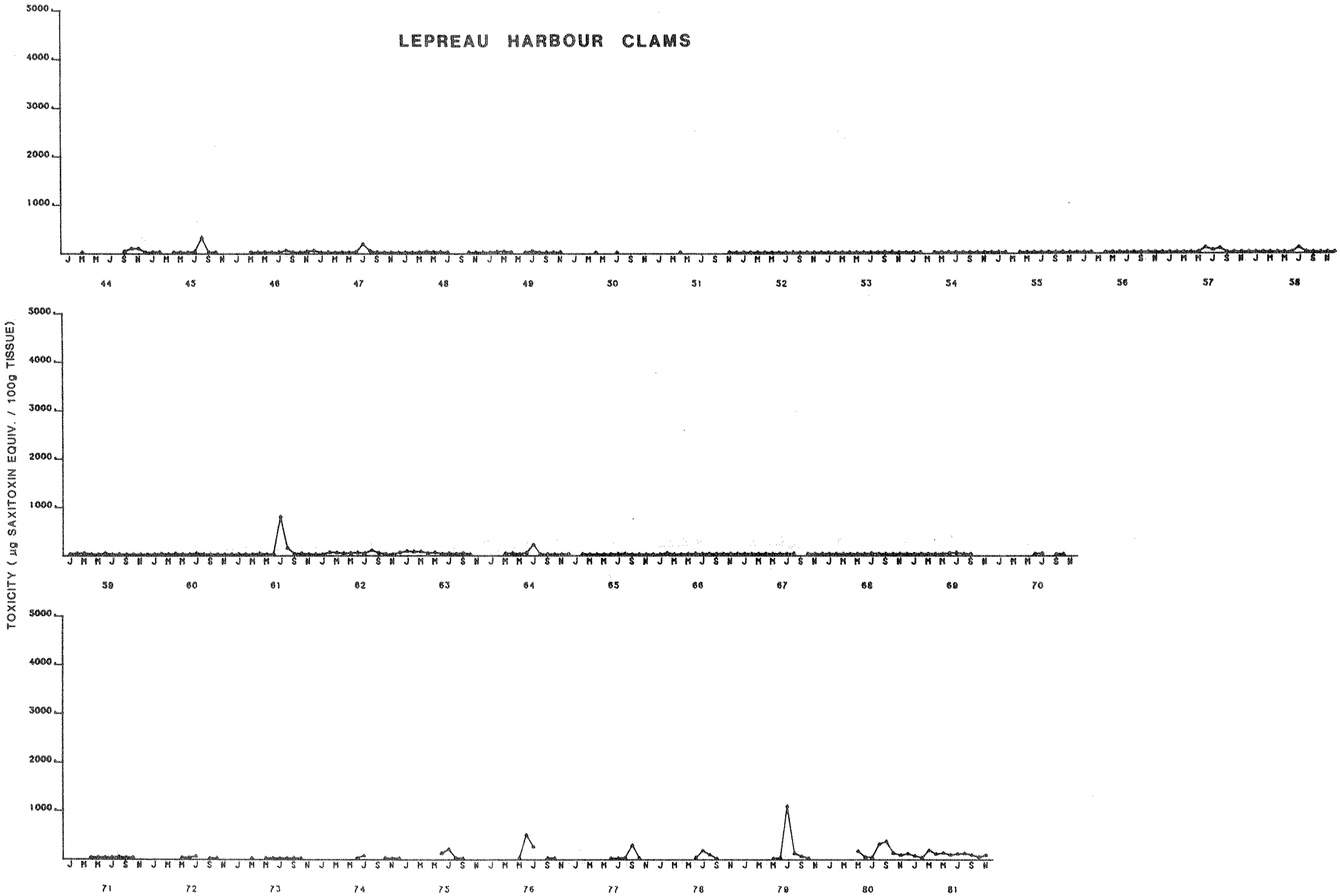

Fig. 6. Mean monthly toxicity of soft-shell clams (*Mya arenaria*) at Lepreau Harbour, 1944-81.

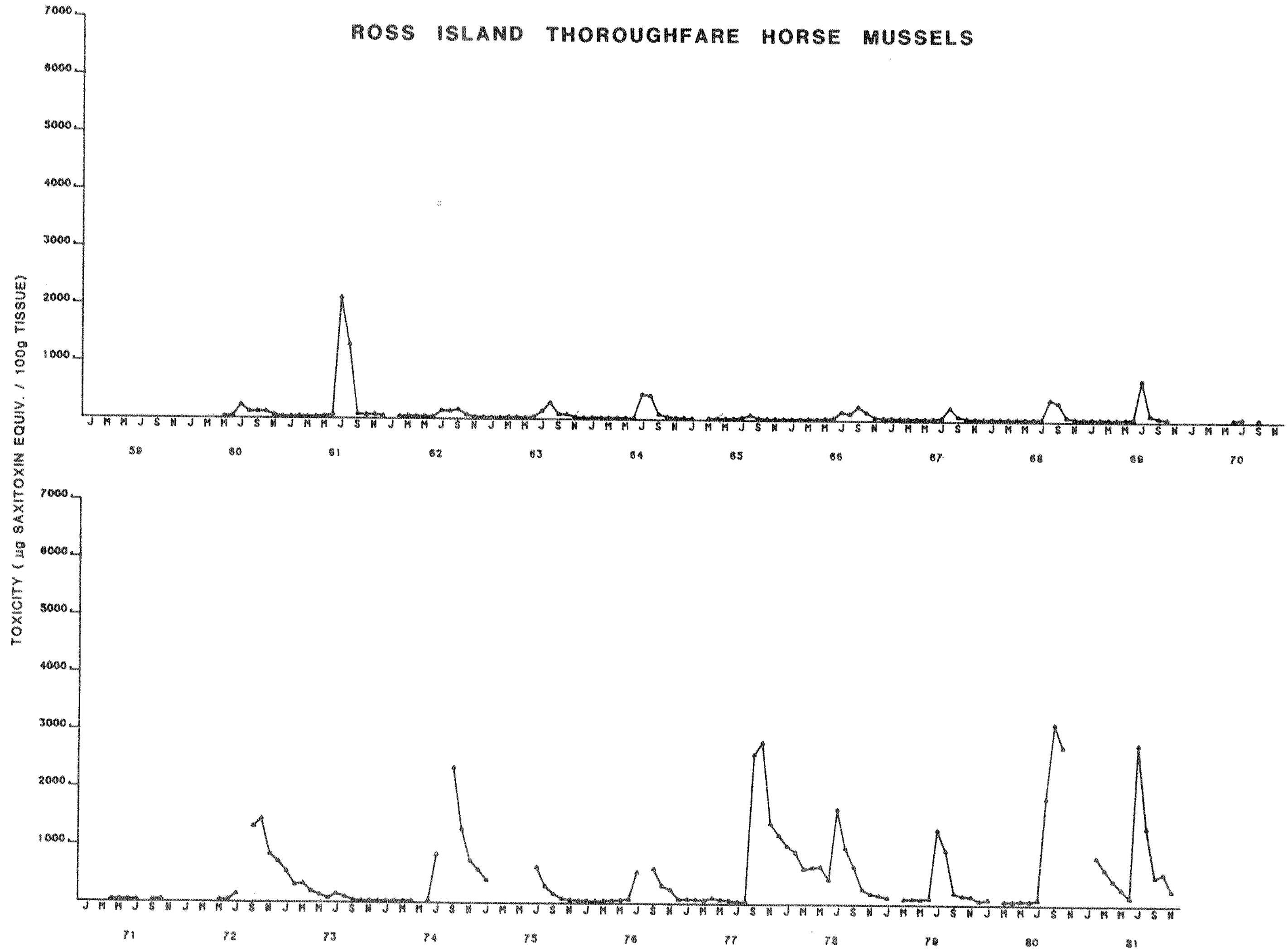

Fig. 7. Mean monthly toxicity of horse mussels (Modiolus modiolus) at Ross Island thoroughfare, 1959-81.

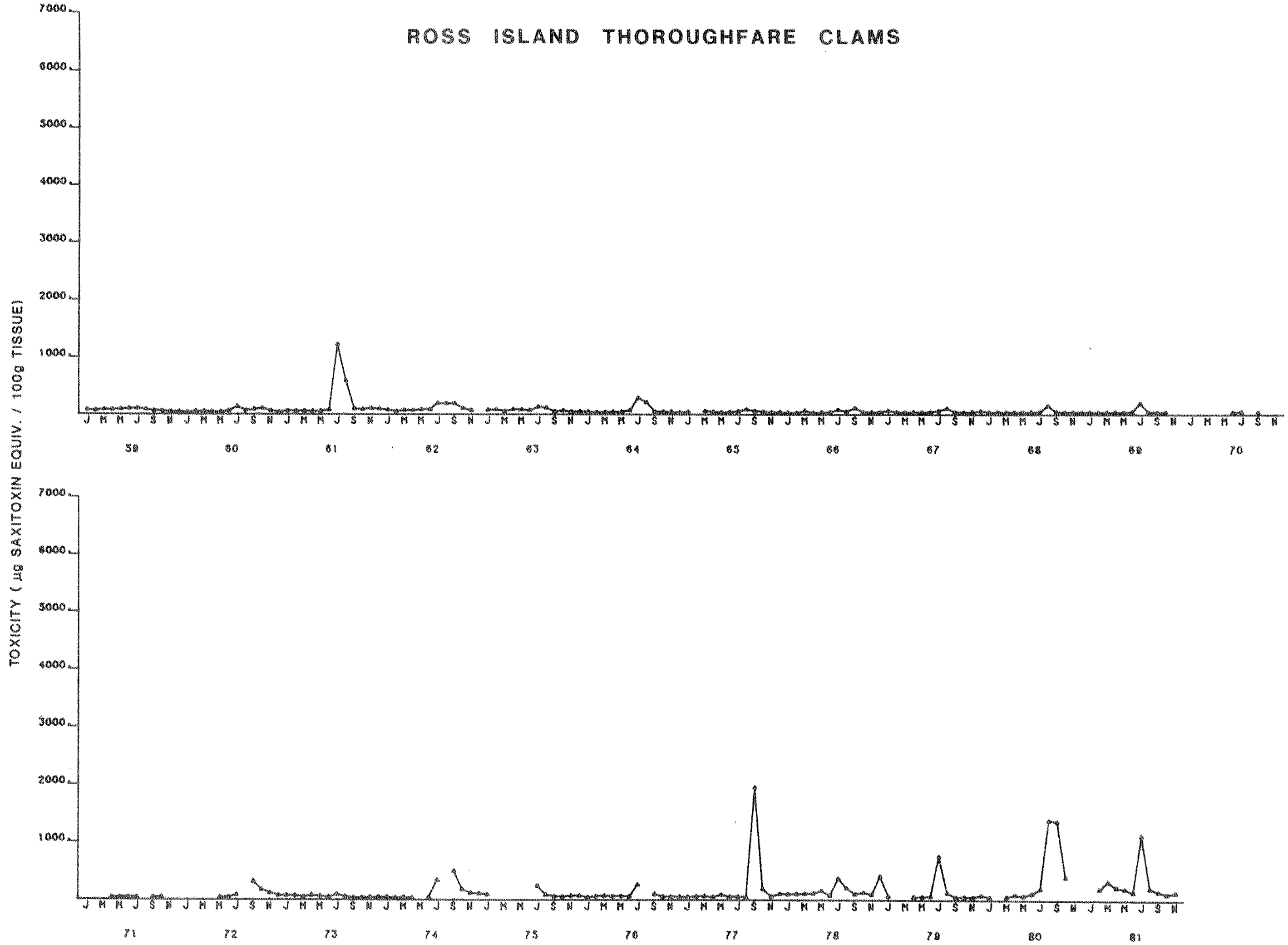

Fig. 8. Mean monthly toxicity of soft-shell clams (Mya arenaria) at Ross Island thoroughfare, 1959-81.

There are two mechanisms by which the extension of toxicity into non-bloom periods can be explained. The first involves the degree and timing of summer toxicity and their consequences for the kinetics of natural depuration of toxins by shellfish. It appears that the high summer toxicity levels in recent years, especially when occurring late in the summer, are associated with prolonged depuration periods and consequent retention of relatively high levels of toxins into the fall months (Fig. 4, 5, 7). If toxicity persists into the late fall when water temperatures decrease rapidly, then depuration of the toxins is probably very slow because of the decreased rate of metabolism of shellfish at low temperatures. In this way shellfish may retain high residual levels of toxins through the entire winter period, until the following spring when temperatures increase and depuration resumes.

A second mechanism for shellfish toxicity in non-bloom periods involves the overwintering, Gonyaulax cysts. Gonyaulax perpetuates itself from one bloom season to the next by forming resting cysts (hypnozygotes). After their formation during the summer bloom, these cysts settle out of the water into the sediment and lie dormant there throughout the fall and winter until the rise in water temperature during the next spring triggers their excystment into the bloom-forming cells (Anderson 1980; Anderson and Morel 1979).

Gonyaulax excavata resting cysts were not described until a few years ago (Anderson and Wall 1978; Dale 1977, 1979). The first study of them in the Bay of Fundy was conducted during the winter of 1980-81 (White and Lewis 1982), after the 1980 bloom developed into red water proportions. This study resulted in several important new findings pertinent to the Gonyaulax bloom and shellfish toxicity problem in the Bay of Fundy. They were the following: (1) the cysts were widely distributed in the sediments of the southern Bay of Fundy, occurring at offshore, inshore, and intertidal locations, (2) an extremely rich deposit of cysts was found offshore in the southwestern Bay of Fundy, with cyst concentrations ranging from 2000 to 8000 cysts per cm^3 wet sediment, and (3) the cysts were found to be toxic - in fact equally as toxic as the motile, vegetative cells.

The significance of these results is considered at length in White and Lewis (1982). In terms of shellfish toxicity, however, the results point to a mechanism by which shellfish can acquire Gonyaulax toxins during the fall, winter, and spring, i.e. through ingestion of the toxic cysts. Cyst ingestion has been considered as a possible mechanism of "off-season" shellfish toxicity for many years (Bourne 1965; Prakash et al. 1971; Yentsch and Mague 1979). Now, with new findings that the cysts are indeed toxic (Dale et al. 1978; White and Lewis 1982) and that cysts have been found continually at intertidal locations along the southwest coast of New Brunswick since they were first looked for in February and March 1981 (White and Lewis 1982; White, unpublished), the evidence is more convincing. It now appears very likely that shellfish can acquire Gonyaulax toxins from ingestion of the cysts, after they have been resuspended in the water by sediment disturbing processes, such as wave and tidal action (especially during storms) and fishing activities.

In summary, the recent intensification of Gonyaulax blooms in the Bay of Fundy has caused an increase in shellfish toxicity not only during the summer, but during the rest of the year as well. The increase in "off-season" toxicity has probably been caused both by the inability of shellfish to depurate entirely their high summer toxin loads and by the ingestion of Gonyaulax cysts which have been produced and deposited in greater numbers since the blooms have intensified.

OVERVIEW OF THE CURRENT SITUATION REGARDING SHELLFISH HARVESTING

The intensification of Gonyaulax blooms has had significant impact on shellfish resource utilization and the shellfish industry in the Bay of Fundy. For about the past eight summers shellfish have become very dangerously toxic, with peak toxicity levels in the range that has been associated with human sicknesses and deaths (Hughes 1979; Prakash et al. 1971; Reyes-Vasquez et al. 1979; Schantz et al. 1955; and PSP case history reports issued by the Fish Inspection Laboratory in Black's Harbour, N.B.). Summer closures of all Bay of Fundy shellfish areas have been necessary during this period. Because of the increased danger from highly toxic shellfish, close surveillance of closed areas for illegal harvesting has also been necessary.

More disturbing, especially in terms of those whose livelihoods depend upon the clam fishery, is the recent trend in which clam areas have been closed during non-bloom seasons as well as during the summer. The situation has become particularly pressing because of the nearly continuous closure of all major clam areas along the southwest coast of New Brunswick (excluding Passamaquoddy Bay) since the early summer of 1980.

During this past fall (1981) there were indications that relief from the prolonged closures was near. In mid-October toxicity values had dropped sufficiently in clams at Lepreau Harbour to allow that area to be opened for harvesting. However, the relief proved to be short-lived. Within a week or so of the opening, toxicity values rose to above the safety threshold so that the area had to be closed again. In December 1981 the same events took place at Pocologan (just southwest of Lepreau Harbour) with reclosure necessary within a week or so of the opening.

A possible explanation for the rapid recontamination of clams with Gonyaulax toxins during these episodes is that the intense clam digging activities upon opening of the areas led to resuspension of Gonyaulax cysts from the disturbed sediments as a result of subsequent wave and tidal action. The toxic cysts were then ingested by clams, causing toxicity levels to rise above the safety threshold. If this explanation is correct, then the same scenario of opening and rapid closing of clam areas may be repeated often in the near future because Gonyaulax cysts are widely distributed throughout intertidal locations in the southwestern Bay of Fundy (White and Lewis 1982; White, unpublished). Of course, patchiness of toxicity within shellfish areas may also play an important role in these events. If so, then some wintertime rises in toxicity levels may be more apparent than real.

COURSES OF ACTION

The prospects for the intertidal shellfish industry in the Bay of Fundy depend upon whether the recent pattern of intensification of Gonyaulax blooms and shellfish toxicity, and of extension of shellfish harvesting closures throughout the year, continues. We do not yet know why the blooms have intensified. It may be a result of natural cycles, or it may perhaps be related to environmental alterations in the Bay of Fundy, such as increased pollution loads. Because the cause of the recent trend is unknown, we are not able to forecast whether blooms are likely to continue to intensify or to abate. Thus it is important to study Gonyaulax blooms and the environmental factors underlying them in order to develop the capability to predict the timing and intensity of the blooms and their consequences for the utilization of shellfish resources.

If the blooms subside and shellfish toxicity returns to the earlier pattern of above-threshold toxicity occurring only during the summer, then the shellfish industry would be able to operate under the same conditions as previously. However, if the blooms continue at their present intensity, or get worse, then new steps will be required to cope with the shellfish toxicity problem. Three possible avenues of approach for dealing with the problem of shellfish which are somewhat above the safety threshold throughout most of the year are suggested below.

The idea of detoxifying (depurating) shellfish contaminated with paralytic shellfish toxins has been considered for many years (Prakash et al. 1971). Preliminary studies suggested that clams and mussels of low toxicity lose about half of their toxin loads after being maintained for 1 wk in Gonyaulax-free seawater (Prakash et al. 1971). Toxin loss may be greater than this if shellfish are subjected to temperature and salinity shocks (Prakash et al. 1971). Detoxification of Bay of Fundy shellfish has not received more serious attention in the past because the shellfish industry was hampered by toxic shellfish and harvesting closures only during the summer. Now, however, with some shellfish areas being closed year-round, there is more incentive for developing economical methods of detoxifying shellfish of low to moderate toxicity.

Some success has been made in using ozonation to detoxify clams (Blogoslawski et al. 1979). But problems remain concerning ozone doses, product marketability, and cost-effectiveness. Ozonation has been successfully used in Europe to depurate shellfish contaminated with bacteria (Blogoslawski et al. 1979). Thus the use of ozonated seawater for shellfish detoxification is an attractive possibility because the same facility could be used for removal of both toxins and bacteria.

A second approach involves modifying the processing or use of shellfish so that low to moderate toxicity presents no problem. Currently most of the clam catch in the Bay of Fundy is marketed fresh. It is well known that the processes involved in commercial canning of clams reduces toxicity considerably. Clams with toxicity values of about 200 μg toxins/100 g tissue, or less, become safe for consumption after commercial canning (Prakash et al. 1971). Thus clams from several areas which are now closed to harvesting because of toxicity levels somewhat above 80 μg toxins/100 g tissue could be dug and marketed if canning facilities were available. Commercial canning of locally dug clams was carried out in this area from at least the turn of the century until the early 1960's. Canned clams represented the mainstay of the shellfish industry until during World War II, when the demand for fresh clams increased. It now appears prudent to consider re-establishing this outlet for Bay of Fundy shellfish. Other potential shellfish markets for which low toxicity would pose no problem, such as using shellfish for bait, should be explored as well.

A third possible avenue concerns the present safety threshold of 80 μg toxins per 100 g tissue and whether or not some relaxation of this threshold during the winter may be feasible. The current limit was established in Canada many years ago and has since been accepted as a sound public-health guideline by international agencies and has been adopted by many countries that have shellfish toxicity problems. Retention of this limit during the late spring-summer-early fall period is especially important because when the Gonyaulax bloom develops, shellfish toxicity can skyrocket within just a few days from below the limit to dangerously high levels. But the question arises whether the limit could be raised somewhat during the winter period, when toxicity rises to dangerous levels are not imminent, without jeopardizing public health. If so, then shellfish areas in which toxicity hovers just above the 80 μg/100 g level during the winter (as has been the recent pattern in several areas) could be opened for harvesting. Because of the potential implications of such action for public health, this possible approach would first have to be considered at length by the regulatory authorities.

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