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PROGRESS OF SHELLFISH TOXIN RESEARCH: IMPLICATIONS OF TOXIC RESTING CYSTS FOR AQUACULTURE

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ABSTRACT

Resting cysts, of toxic dinoflagellates responsible for PSP, behave as fine silt particles within the sedimentary regime; some areas act as "sinks" for collecting them, while other areas remain relatively cyst-free. We are discovering large concentrations of toxic resting cysts in bottom sediments along the Maine coast, and they have been reported as far south as Long Island Sound. This calls for a new approach to the shellfish toxicity problem. Resting cysts probably account for shellfish toxicity where there is no obvious link with motile dinoflagellates (for example, in deeper waters, or in winter), and they probably contribute significantly to toxicity following blooms. If so, then the monitoring of plankton for shellfish toxicity will have to be broadened to include benthic resting cysts and the sedimentary process, and the practice of transplanting shellfish from one geographic area to another needs re-evaluation. Aquaculturists must be concerned about the implications: (1) that shellfish can become toxic by ingestion of cysts directly; and (2) that the distribution of toxic dinoflagellates can be spread to areas currently toxin-free by the transplanting of shellfish which contain mud with cysts of toxic species.

INTRODUCTION

Several coastal waters along North America are subject to sporadic increases in the density of toxin-producing algae of the genus Gonyaulax (see Figure 1). The various toxins elaborated by some of these algae may be accumulated by bivalve molluscs of commercial interest. Although most shellfish species are themselves relatively unaffected by the accumulated toxins, they present a threat to public health because human intoxication can result from consumption of these shellfish while they contain the toxins. The resulting intoxicated condition in humans is known as Paralytic Shellfish Poisoning (PSP). There are medical records of over 1,650 cases of this food poisoning worldwide which have resulted in at least 300 fatalities.[5] Tingling lips and fingertips, dizziness, respiratory difficulties, and loss of equilibrium are symptomatic of PSP.[10] In extreme cases, intoxication can lead to respiratory arrest and death.

Shellfish from most of the major growing areas of North America, however, contain high levels of these toxins for only short periods of the year; and during some years, toxin levels remain low enough so that they are not detected in many areas. Programs to monitor for the increase of toxins in shellfish are currently in effect to permit selective closures which allow resource harvesting to proceed with the least possible interruption.

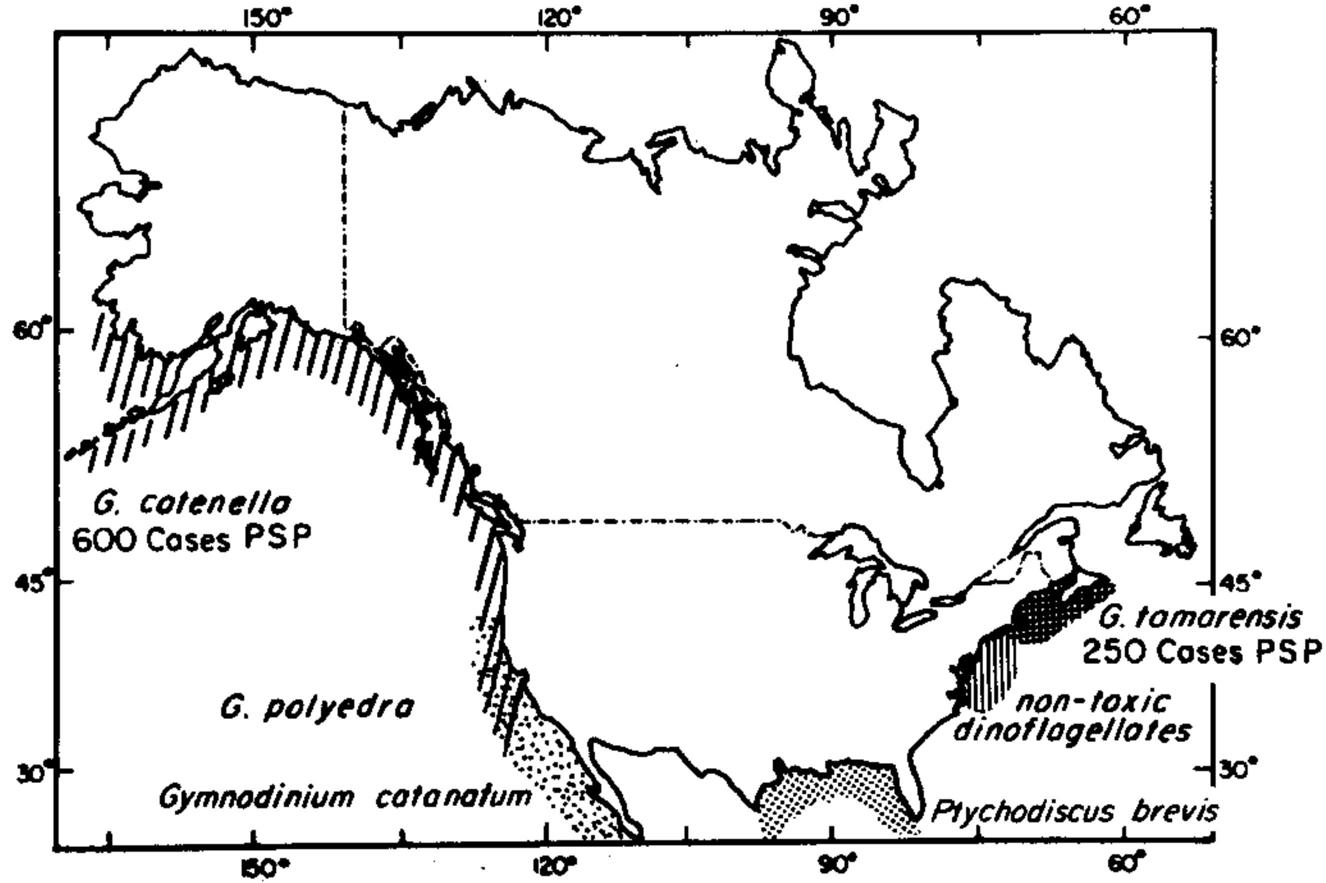

Figure 1 Coastal waters of North America and common distribution of species of Gonyaulax and other red tide dinoflagellates.

With expanded research, the timing and location of significant toxin levels in shellfish are becoming increasingly predictable, providing benefits to the future management of natural beds and to the development of aquaculture practices and the selection of aquaculture sites.

With the onset of a toxic dinoflagellate outbreak, the closing of a shellfishery sets off a barrage of problems which include not only individuals involved with the fishery itself, but the public as a whole.[11,14] The outcry often vented against these closures is whether or not the established standards are too conservative. Of course, the shellfish industry by way of its own public relations is at stake; a severe outbreak of PSP caused by consumption of marketed toxin-bearing shellfish could lead to unrecoverable economic disaster for the shellfisheries in general.

At the moment, public health protection from PSP is under control, but there are other problems which must be addressed. There can result collapse of local fisheries and related industries. Socio-economic impacts are more frequent, widespread and longer lasting. These may be direct, e.g., the closure of the Alaskan clam fishery in 1947 (with a very limited reopening in recent years), or more recently the closure in 1972 and subsequent years in New England and 1978-79 in Puget Sound, or indirect, e.g., adverse consumer reaction to fishery products or tourist sites following a red tide. Both can span several years and affect communities some distance from the bloom site. Furthermore, pressures to develop alternatives or replacement fisheries at new locations may seriously affect the long-term economic stability of areas experiencing red tides.

The crisis nature of the problem, and the long standing concerns over the consequence of periodic blooms of toxic dinoflagellates, including their recent occurrence in new geographic areas, underscores the need for an organized collaborative effort to place these events in their proper scientific perspective. With the toxin reported from new locations, it is uncertain whether or not the apparent spreading of shellfish toxicity is a function of our increased awareness and monitoring zeal or a real phenomenon, since many countries and regions have not had long, ongoing programs studying the problem. It is equally uncertain whether or not the increased appearance of red tide problems is due to man's activities (pollution or inadvertent "seeding" via shellfish transplants) or whether these are merely natural events with long-term periods which have not been measured before.

Recently workers have begun to look more closely at the organisms responsible for the production of the toxins. The identification is complex and dependent on strict attention to minute details. As of this writing, there is no consensus as to whether the observed differences are diagnostic of apparent species, strains, forms or varieties. In addition to the taxonomic considerations, it is ecologically important to discern whether the different "types" have different environmental preferences and whether differences in cellular toxin levels result from differences in environment, or differences in genetic "type." Toxin levels in *Gonyaulax* spp. have been observed to vary dramatically from nontoxic[26] through highly toxic.[1,7,22]

Recent developments also have caused a resurgence of interest in the life history of the organisms involved. It is known that, in addition to the motile form present in New England waters from mid-April to mid-October, G. tamarensis produces a naturally occurring resting cyst. These cysts are the result of sexual reproduction.[24] They lack flagella and sink rapidly and accumulate in the flocculent layer at the sediment-water interface where they overwinter. The nearly neutral density of these cysts renders burial in the sediments unlikely. When wind-mixing disturbs the surface sediment, resettling occurs with the heaviest particles first, and the cysts last. These cysts appear to act as other sedimented particles, sorting out by particle size and density into "sinks" and have been used by some investigators to identify water movement patterns.[33] A resting period of 4 months appears to be mandatory,[4] yet in some cases duration varies with temperature of storage, and can be as short as one month.[2]

Measurement of toxin levels in resting cysts indicates levels at least ten times higher than those of motile cells.[6] Cysts have been found in the water column during periods of strong vertical mixing.[28] Large concentrations of highly toxic resting cysts have been discovered in bottom sediments along the Maine coast[13] and have been reported in the literature as far south as Woods Hole, MA.[3] Distribution and occurrence along the Pacific Coast is not as well known, but cysts have been reported from the Puget Sound area[29] and from Alaska.[30]

The presence of these highly toxic cysts calls for a new approach to understanding shellfish toxicity problems.[6,21] Evidence suggests that resting cysts may account for shellfish toxicity even when no motile dinoflagellates occur in the water column (Figure 2). Such cysts may also contribute to high toxicity in shellfish when both motile cells and cysts are in the water column. Examples of organisms exhibiting winter toxicity, which also suggest ingestion of cysts, include deep sea scallops (Placopecten magellanicus) at a depth of 100 m in the Bay of Fundy[20,31] and butter clams (Saxidomus giganteus) and mussels (Mytilus edulis) from Haines, AK.[32]

Recent findings about cysts serve to emphasize that red tides, that is, discolored water, are by no means diagnostic of toxic conditions because: (1) shellfish can accumulate harmful amounts of toxin even at Gonyaulax concentrations below those necessary to discolor water; (2) shellfish can intoxify when no motile cells are detected in the water column, but when cysts of the causative organisms are present;[28] and (3) red tides can result from concentrations of other, non-toxic dinoflagellates[26] or ciliates.[16,19]

While dense concentrations of toxic dinoflagellates may result directly from seed beds of cysts, followed by rapid growth of the algal populations, physical (hydrographic) mechanisms also appear to be important. These concentrating mechanisms are unique in that they require no rapid reproduction. Instead, they provide a means for delivery of existing populations to a specific area where biological behavior, such as positive phototaxis, can result in dense concentrations.[15,17,23,25] These mechanisms may be triggered by meteorological events, such as rainfall and wind.[8,17,27]

Recent physical data suggest that frontal zones, or discontinuities between water masses, are the locations most likely to generate red tides.[9] These fronts may result from tide- or wind-generated convergences and/or density discontinuities; they are frequently marked by pronounced differences in the vertical stability of the two water masses.[12,18,23,25]

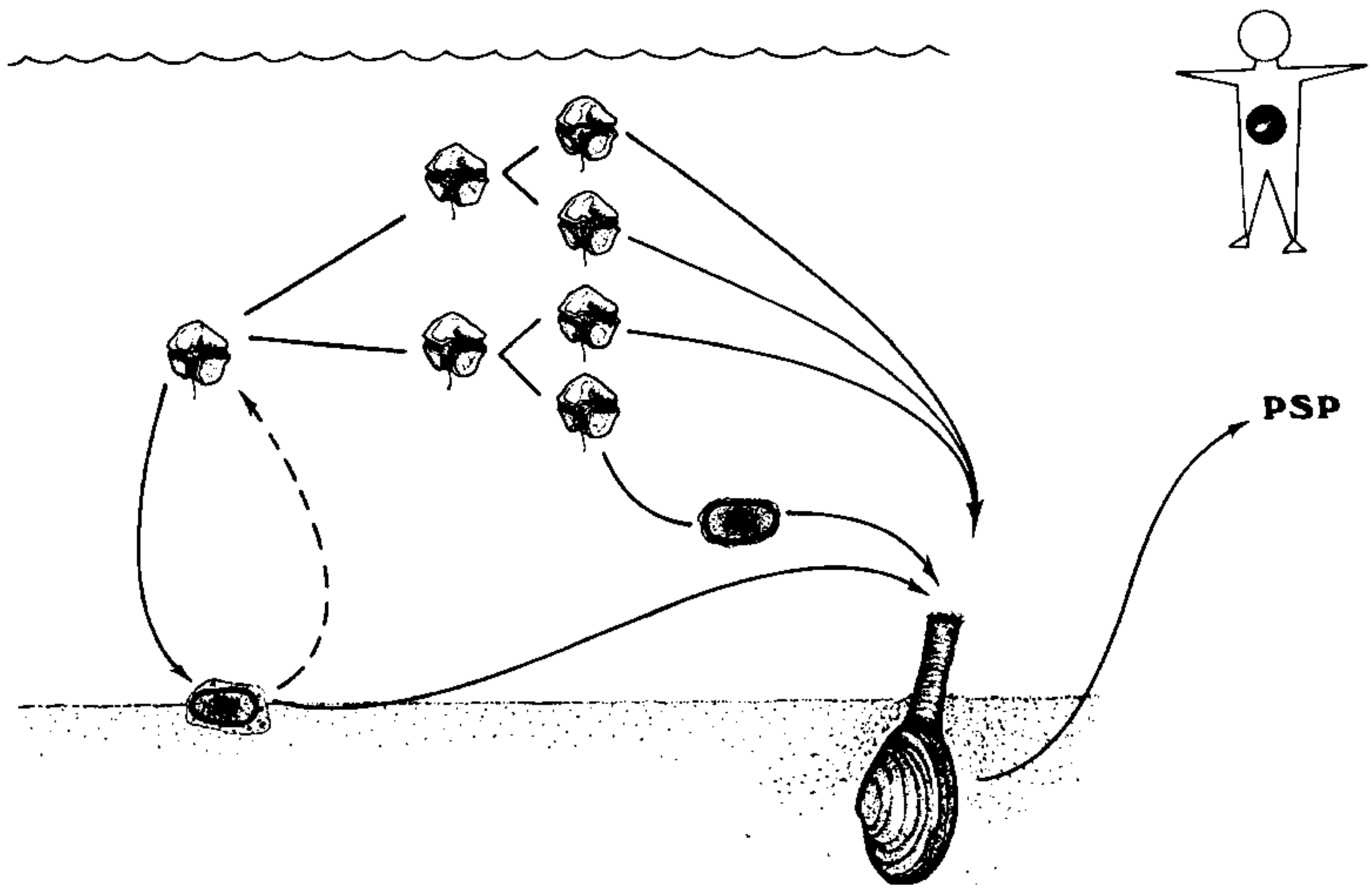

Figure 2 Motile cells developing into cysts, and their role in perpetuating shellfish toxin, leading to PSP in humans (from reference 4).

Fronts can be detected in surface temperature differences which can be sensed by infra-red carried aboard small aircraft or via TIROS, GOES and other satellites. These fronts may also produce surface and/or water column chlorophyll maxima which can be detected by the CZCS (Coastal Zone Color Scanner) system.

The Monhegan Island area off the coast of Maine has been studied intensively by our research group over the past five years. The progress is given diagrammatically in Figure 3 a-e.

Despite our increasing knowledge of dinoflagellate ecology, it is still not possible to predict specific toxin occurrences. In recent years, toxic shellfish have been found in areas where toxins had been previously unknown; it thus appears that no guarantees can be made for toxin-free locales. In areas that to date have witnessed no shellfish toxin, dinoflagellates routinely bloom, and there is fear that a toxic species might replace a non-toxic species. It is, therefore, unrealistic for commercial management to focus attention only on areas historically free from shellfish toxins.

The current thought on developing a predictive index for shellfish toxin is changing from the original concept of monitoring dinoflagellates in the plankton to the general concern for long-term studies on climatological and satellite-sensed hydrographic factors which may favor "blooms" of dinoflagellates. The fact that cysts are now being implicated as a cause of shellfish toxicity complicates the predictive index concepts, but increases our understanding of toxin occurrences in nature. This, in turn, should lead to better approaches to managing shellfish resources.

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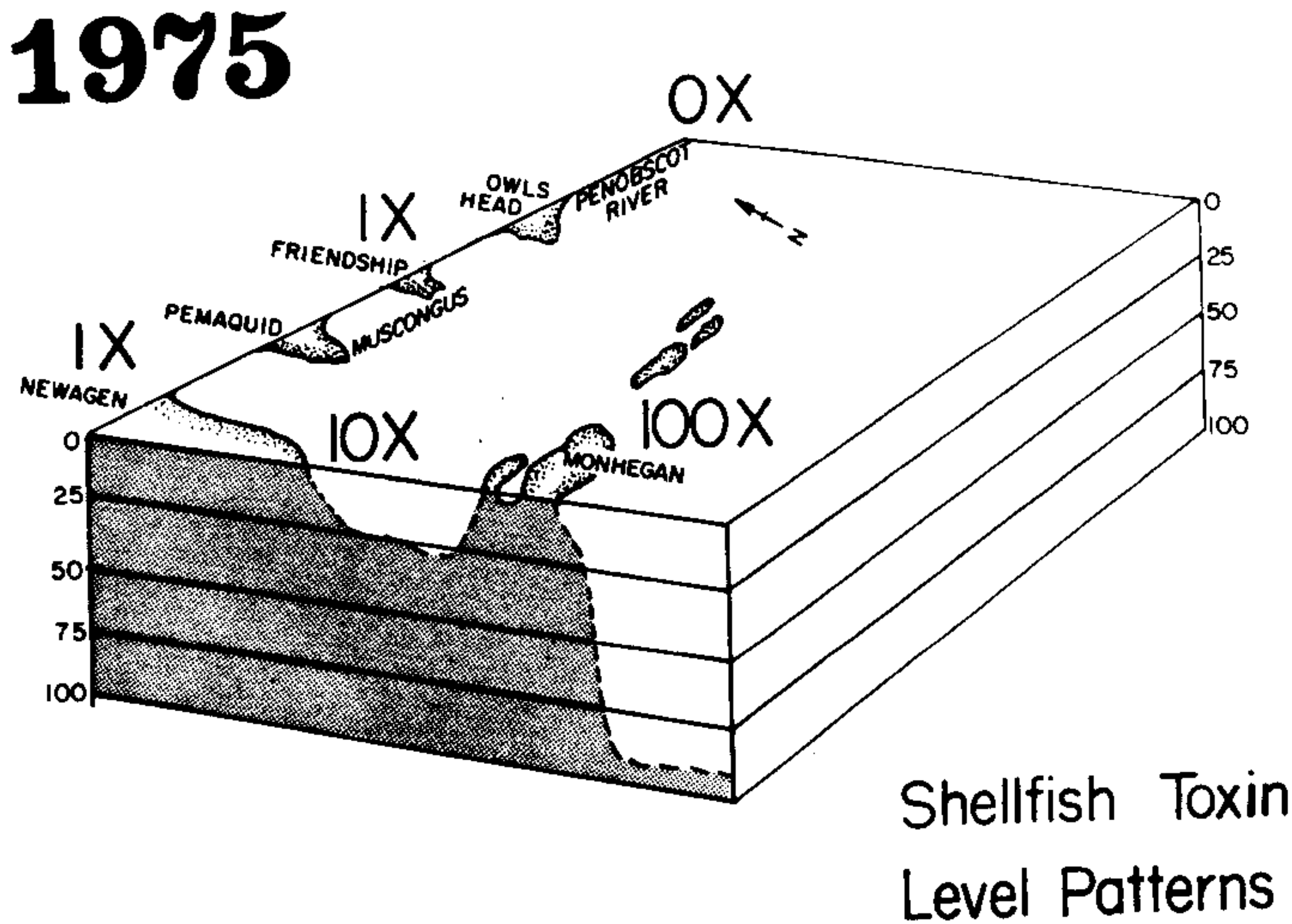
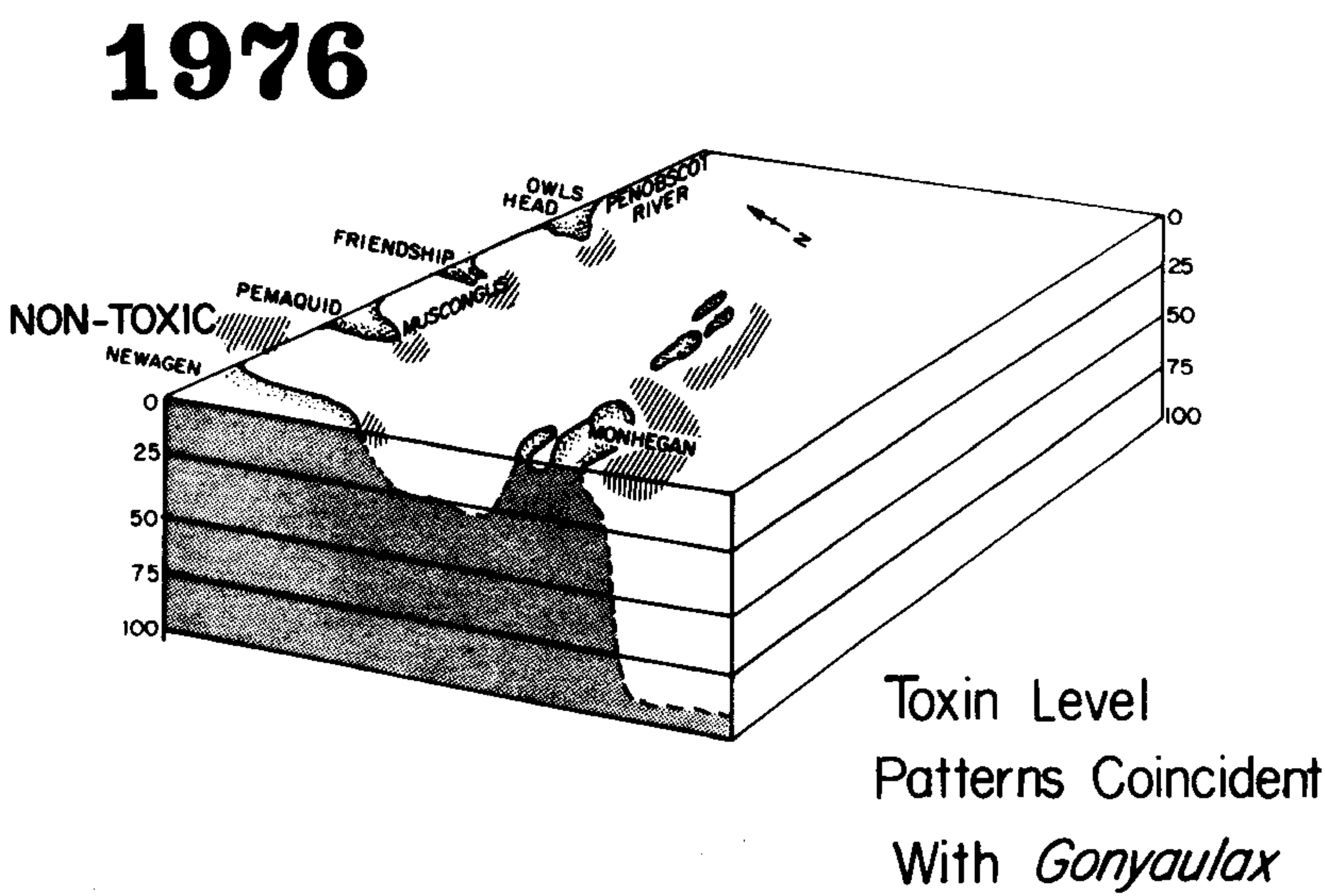


Figures 3a-3e Diagrammatic representation of findings 15 miles offshore near Monhegan Island, Maine. Depth is in meters.

Figure 3a 1975 -- Patterns of toxicity reflected that island systems are 100X the toxic levels of bays. The region east of the Penobscot River is virtually toxin-free.



.Figure 3b 1976 -- Patterns of toxin level were found to be coincident with motile Gonyaulax in the water column. The one exception was the Damariscotta Estuary, between Cape Newagen and Pemaquid. In that region, there was extensive blooming of a non-toxic Gonyaulax.

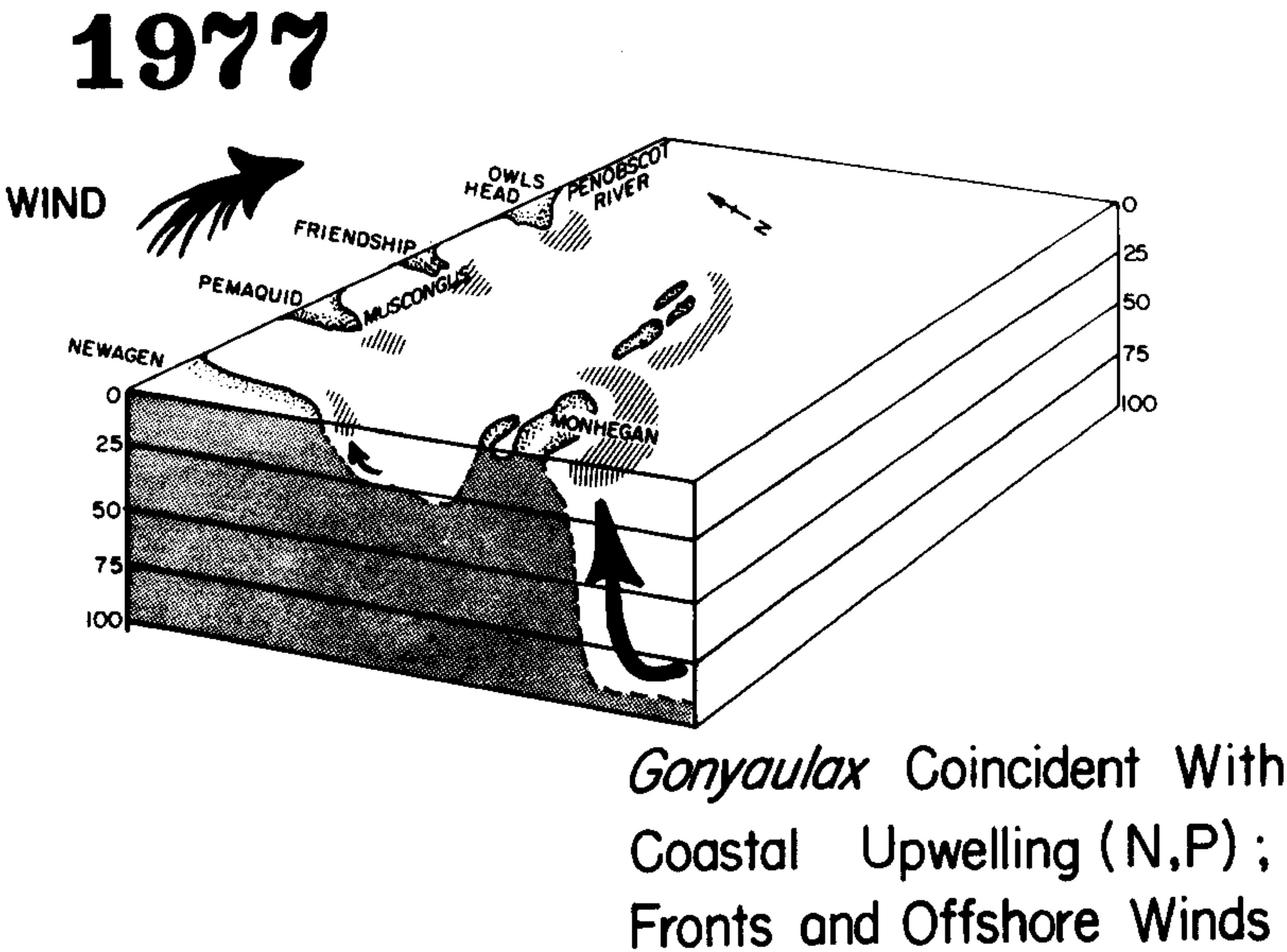


Figure 3c 1977 -- Coastal upwelling was documented which was driven by offshore winds. Surface <u>Gonyaulax</u> populations were most abundant in frontal regions.

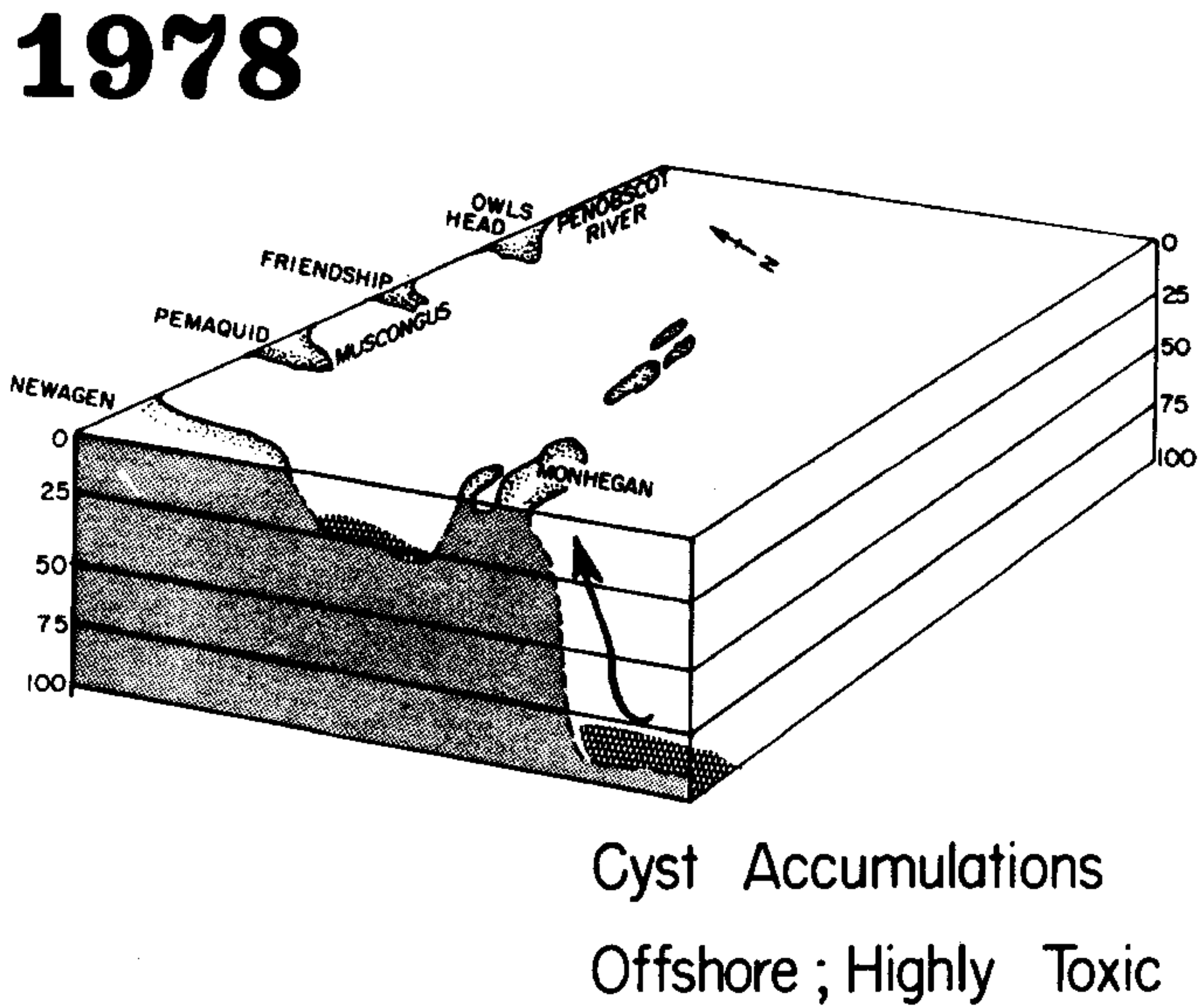
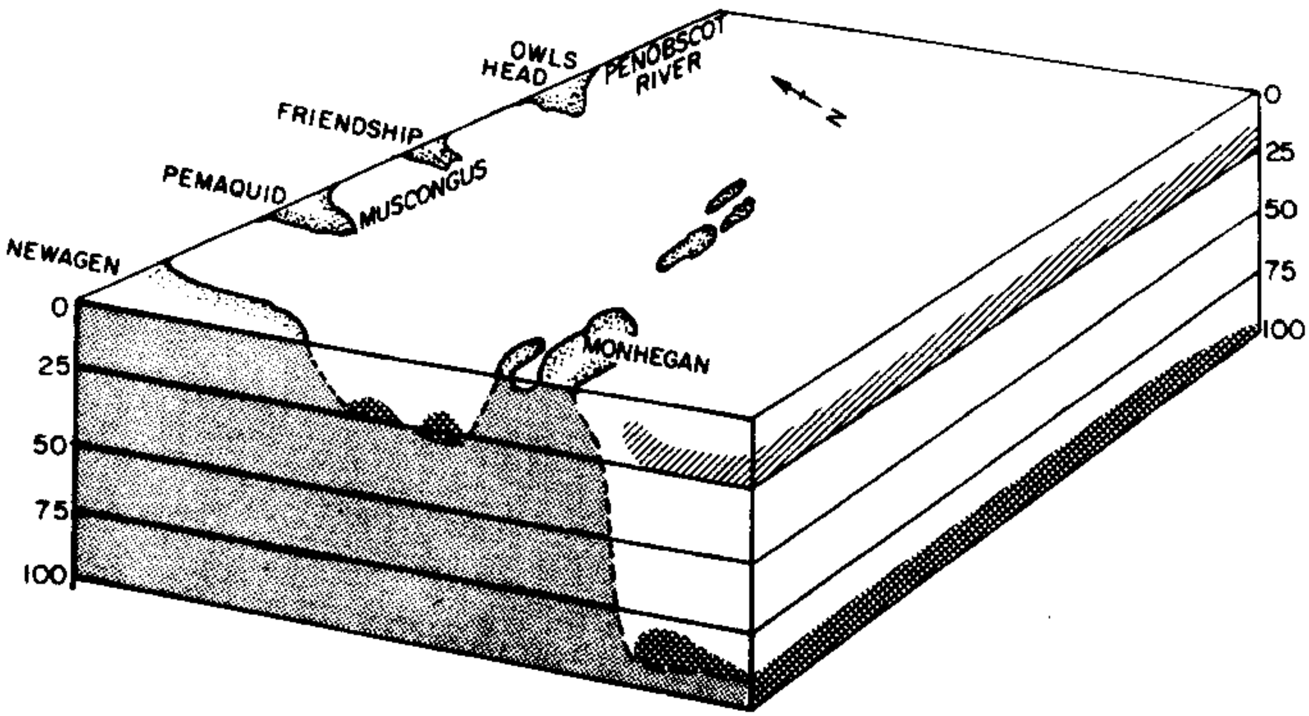


Figure 3d 1978 -- Winter cyst accumulations were found offshore and were demonstrated to be highly toxic.

1979



Cyst Distribution General Offshore;
Dinoflagellate
Subsurface Maxima - Offshore Fronts

Figure 3e 1979 -- Cyst distribution was found to be general offshore in the sediments, both winter and summer; and motile dinoflagellates were found in extensive subsurface maxima. No surface patches were reported.

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