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CALIFORNIA'S PARALYTIC SHELLFISH POISONING PREVENTION PROGRAM, 1927–89

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ABSTRACT Paralytic shellfish poisoning (PSP) was made a reportable condition in California in 1927. Since then, 510 cases, including 32 deaths, have been reported to California health authorities. Expansion of California's commercial shellfishing industry and growing numbers of people involved in sport shellfishing activities in recent years have heightened concerns about PSP and prompted the authors to review the State's PSP Prevention Program.

The California PSP Prevention Program is the oldest such program in the United States and is currently comprised of: (1) a mandatory reporting requirement for PSP, (2) an annual quarantine on sport-harvested mussels, (3) a coastal shellfish monitoring program, (4) PSP testing requirements for commercial shellfish harvesters, and (5) a public information program. Overall, the program appears to have been successful in controlling the occurrence of PSP in California, but it is challenged by the seemingly changing pattern of dinoflagellate blooms along California's coast and a substantial migration to California of persons unfamiliar with PSP or accustomed to harvesting shellfish in areas where PSP is not a problem.

This report presents information on the seasonal occurrence, geographic distribution, and types of shellfish involved in PSP illnesses in California. In addition, data from the coastal shellfish monitoring program are used to describe the frequency, intensity, seasonal occurrence, geography, and dynamics of toxic dinoflagellate blooms along the California coast. Also noted are differences in toxin levels in mussels, oysters, and other types of shellfish exposed to the same bloom conditions. Toxic bloom characteristics and changes in commercial and sport shellfishing activities are discussed in relation to PSP risks and the State's PSP Prevention Program.

KEY WORDS: PSP, *Protogonyaulax*, *Gonyaulax*, oysters, *Crassostrea*, mussels, *Mytilus*, shellfish.

INTRODUCTION

Paralytic shellfish poisoning (PSP) is an acute, sometimes fatal form of food poisoning that has been a public health concern in California for many decades. The syndrome is caused by eating mussels, clams, oysters, and other filter-feeding marine bivalve mollusks that have become poisonous from ingesting certain marine dinoflagellates that contain saxitoxin and related biotoxins. The dinoflagellate of concern along California's coast is *Protogonyaulax catenella* (Whedon and Kofoid 1936, Taylor 1979), formerly known as *Gonyaulax catenella*.

P. catenella normally exists in the marine environment as dormant cysts in bottom sediments or as motile cells comprising a minor part of the plankton community. Under certain conditions, however, the dormant cysts may germinate, and the resulting motile forms, or active cells already present in low concentration, undergo periods of rapid population growth (Dale and Yentsch 1978, Anderson 1984). During these periods of proliferation, or dinoflagellate "blooms," coastal shellfish may become toxic.

Because most marine dinoflagellates possess brown or reddish pigments, dense populations in bloom areas may cause the ocean to take on a similar color. From this appearance has developed the popular association of poisonous shellfish with so-called "red tides." However, many red tides are caused by nontoxic dinoflagellates, and in California water *P. catenella* may be abundant enough to cause toxicity problems in shellfish without causing noticeable discoloration of the water (Carlisle 1968, Price 1989).

Saxitoxin and the related compounds causing PSP are among the most potent poisons known (Shimizu 1979, Hall and Reichardt 1984). The oral LD_{50} of saxitoxin for mice is about 263 $\mu g/kg$ (WHO 1984). A fatal oral dose for humans is only a few milligrams. Like tetrodotoxin, saxitoxin blocks the sodium channels of nerve membranes, and thereby inhibits neuronal transmission (Evans 1975, Schantz 1986; WHO 1984).

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Symptoms of PSP usually begin within 15 to 90 minutes after ingesting toxic mollusks and most often consist of paresthesia and numbness of the tongue, lips, and fingertips. If the dose is sufficient, this may be followed by muscular incoordination, a "floating" sensation, diplopia, dysarthria, and, in advanced cases, ascending paralysis. Death may result from diaphragmatic paralysis and respiratory failure within 2 to 12 hours (CDHS 1983, Halstead and Schantz 1984).

The clinical manifestations of PSP and the severity of symptoms depend upon the concentration of the toxin in the shellfish and the amount of shellfish consumed. There also appears to be substantial individual variation in susceptibility to the toxin. However, available data do not support the belief (McFarren et al. 1960) that persons who commonly eat shellfish in affected areas may develop resistance to the toxin (Halstead and Schantz 1984).

According to Tennant et al. (1955), severe symptoms have occurred following ingestion of as little as 124 μg of toxin, and death has resulted from the ingestion of about 456 μg. Bond and Medcof (1957) cite a case of a two-year-old child suffering serious poisoning after ingestion of clams containing only 96 μg. In the same incident, two adults had mild symptoms after consuming an estimated 340 and 344 μg each, and a severe poisoning resulted from ingestion of about 880 μg. Evans (1975) states that symptoms usually are not felt by adults unless more than 360 μg (2,000 mouse units) are ingested, while serious illness is likely following ingestion of more than 900 μg (5,000 mouse units). Schantz et al. (1975) propose that severe illness, and even death, may occur after ingestion of 500 to 1,000 μg. At the more conservative end, Dale and Yentsch (1978) suggest that moderate symptoms should appear upon the ingestion of 1,000 μg of toxin, with the lethal range beginning at about 10,000 μg.

Although the literature offers a range of opinions regarding the clinical implications of ingesting various levels of PSP toxin, and while there seem to be wide differences in human susceptibility to the toxin, it is reasonable to extrapolate that ingestion of 200 to 500 μg is likely to cause at least mild symptoms; ingestion of 500 to 2,000 μg is likely to cause moderate to severe symptoms; and consumption of more than 2,000 μg is likely to produce serious, and possibly lethal, consequences.

CDHS recognizes that dose-response studies tend to concentrate on average dosages required to produce symptoms of various severities, rather than on minimum dosages which may affect highly susceptible persons. As stated by Bond and Medcof (1957): ". . . such averages can hold only academic interest in the minds of those responsible for preserving public health. They must concern themselves not merely with protecting the average person, but also those who are more susceptible to the poison than average."

All testing for PSP in California is done by the California Department of Health Services, with toxin levels being determined by the standard mouse bioassay method (AOAC 1984).

The detection level for PSP toxins, using the mouse bioassay, is about 40 μg per 100 grams of shellfish meat. The U.S. Food and Drug Administration "alert level" for PSP toxin in commercial shellfish is set at 80 μg. That is, shellfish having levels of toxin at or above 80 μg/100 g are considered unsafe and not allowed for sale (Clem 1975, NSSP 1988). This alert level is purposefully conservative to allow time to implement regulatory actions (e.g., closure of commercial shellfishing beds or recall of product from the marketplace) before toxin levels increase to more dangerous concentrations.

Historical Background

PSP has been recognized as a health risk to consumers of bivalve shellfish in the temperate zones of North America and Europe for many centuries. Reports dating back to the eighteenth century describe numerous human illnesses resembling PSP following consumption of shellfish in Northern Europe and Great Britain (Halstead 1965).

In North America, Indians of the Pacific Coast apparently were aware of the relationship between red tides and bioluminescence in ocean waters and toxicity in shellfish. They would not eat shellfish when these conditions appeared (Meyer et al. 1928). Illustrative of this, in 1928, Meyer et al. wrote:

> "From time immemorial it has been the custom among coast tribes of Indians, particularly the Poma, to place sentries on watch for Kal ko-o (mussel poison). Luminescence of the waves, which appeared rarely and then only during very hot weather, caused shellfishing to be forbidden for two days; those eating shellfish caught at such times suffered sickness and death. . . . According to a report a band of Indians died about fifty years ago from eating mussels gathered on the Mendocino coast during the month of August."

The first seemingly documented case of PSP in North America occurred in 1793, when five members of Captain George Vancouver's crew became ill after eating mussels collected near Fitzhugh Sound in what is now British Columbia (Quayle 1969). One of the five died. Vancouver's account of this event appears to be the first detailed written description of the symptoms and progression of paralytic shellfish poisoning (Vancouver 1801).

In 1799, it is reported that 100 Aleut hunters accompanying the Russian Baranoff Expedition died after eating a meal of mussels collected near present-day Sitka, Alaska (Halstead 1965). This event is not well documented, and some have suggested that the descriptions given are not sufficiently detailed to exclude other possible causes (McFarren et al. 1960). If this outbreak actually was PSP, it represents, by far, the greatest number of fatalities ever known to have resulted from a single PSP outbreak. Although there are no official reports of PSP incidents in California during the early years of European settlement, Meyer et al. (1928) and Sommer and Meyer (1937) state that PSP cases were not uncommon during the latter half of the nineteenth century in California. Sommer and Meyer (1937) wrote:

> "In order to visualize the significance of shellfish poisoning as a problem of health on the Pacific Coast, it is well to remember the following facts: During and following the investigation of the outbreak that occurred in 1927, numerous communications from physicians and other persons brought out the fact that mussel poisoning along the northern coast of California is a rather common phenomenon. Besides those recorded previously, numerous single and group intoxications are recalled by the inhabitants. Mass intoxications in Indians and single ones in white settlers which occurred about fifty years ago are also well remembered."

The first PSP outbreak recorded in California, and for the United States outside Alaska, involved 12 persons who ate mussels from Timber Cove, Sonoma County, in 1903 (Meyer et al. 1928). Five of these persons died. Subsequently, 4 cases were reported from Santa Cruz County in 1915, and 12 cases, including 2 deaths, in 1917. An additional case in San Diego County was reported in 1918.

It was not until 1927, however, that health officials in California fully recognized the serious potential of PSP. In that year, a major outbreak occurred along the San Francisco coast, extending from Sonoma to Monterey Counties. In total, 102 cases were reported, including 6 deaths (Meyer et al. 1928).† As a result of this outbreak, PSP was made a mandatorily reportable condition in California.

Since the 1927 California epidemic, interest in PSP in the United States and worldwide, has waxed and waned, with periodic reports being made of PSP incidents (Meyer et al. 1928, McFarren et al. 1960, Halstead 1965, and Rippey and Verber 1986). On reviewing the worldwide data, it is clear that the California coast is a region of especially high risk for PSP. It is an area which ranks high in the number of reported PSP cases and deaths (Table 1). Despite this, and the fact that California's PSP Prevention Program is the oldest such program in the United States, California's experience in preventing this public health problem has not been previously reported.

TABLE 1.

Number of reported incidents of PSP in North America during the period 1900 through 1989.[a]

Area	PSP Illnesses (Deaths)
Alaska	174 (7)
British Columbia	103 (5)
Washington	36 (3)
Oregon	>22 (1)
California	539 (39)
Mexico[1]	>18 (3)
Guatemala[2]	>175 (26)
Rhode Island	1
Massachusetts	73
New Hampshire	6
Maine	>98
Nova Scotia and New Brunswick	107 (2)
Quebec	46 (4)
New Foundland	1

[1] A single outbreak near Mazatlan, Sinaloa, in 1979. The causal dinoflagellate was identified as *Gymnodinium catenatum* Graham.
[2] A single outbreak near Champerico, Retalhuleu, on the Pacific coast of Guatemala in 1987. The causal dinoflagellate was identified as *Pyrodinium bahamense* var. *compressa*.
[a] From Rippey and Verber, 1986, plus recent records. Illnesses and deaths from neurotoxic shellfish poisoning (NSP) and amnesic shellfish poisoning (ASP) are not included.

CALIFORNIA PSP PREVENTION PROGRAM

Since its inception over sixty years ago, the California Department of Health Services (CDHS) PSP Prevention Program has incrementally evolved into its current five-pronged approach, consisting of a mandatory reporting requirement for PSP cases, an annual mussel quarantine, a coastal shellfish monitoring program, testing requirement for commercial shellfish harvesters, and a public information program (CDHS 1989). Closure of commercial shellfishing operations, special quarantines of defined areas, and public warnings against consumption of sport-harvested bivalves are based on the findings of the coastal monitoring and commercial testing programs. These elements are described below.

1. *Mandatory Reporting of PSP Cases*

As already noted, PSP was made a mandatorily reportable condition in California in 1927. Since then, 510 cases, including 32 deaths, have been reported to CDHS. A summary of these cases is given in Table 2.

The number of cases associated with various kinds of shellfish is shown in Table 3.

2. *Annual Mussel Quarantine*

CDHS initiated its annual six-month (May 1 to October 31) mussel quarantine in 1942 (CDPH 1942). This action followed previous more limited quarantines and public warnings about the eating of mussels and clams during the summer months. These earlier quarantines, dating back to 1927, were based on shellfish testing results and occurrences of PSP illnesses, and they covered different periods each year. The known danger period was gradually expanded from July and August to its current May through October period as elevated shellfish toxin levels and human PSP cases were reported earlier and later in the year.

†Meyer et al. 1928, and Sommer & Meyer, 1937, both give 102 as the total number of cases in the 1927 outbreak. Some time later, a single additional case was attributed to this year, giving a total of 103. As noted by Meyer et al. 1928, the total of 102 "is only approximate" and "it is not unlikely that only the severe and moderately severe forms of illness have been recognized and tabulated."

TABLE 2.

Reported human cases of paralytic shellfish poisoning in California, 1927–89.

Year	Cases	Deaths	Counties Involved[1]	Type of Shellfish
1927	103	6	Sonoma, Marin, San Mateo	Mussels
1929	60	4	Sonoma, Marin, San Mateo	Mussels (54 cases, 1 death) Clams (6 cases, 3 deaths)
1930	2	0	Sonoma	Mussels
1931	2	0	Unknown	Mussels
1932	44	2	Mendocino, Sonoma, Marin, San Mateo, Monterey	Mussels (41 cases, 1 death) Clams (2 cases, 0 deaths) Unknown (1 case, 1 death)
1933	12	0	Del Norte, San Mateo	Mussels
1936	3	2	Ventura	Mussels
1937	27	0	Sonoma, Santa Cruz, Monterey	Mussels
1938	3	0	Ventura	Mussels
1939	76	8	Santa Cruz, Monterey	Mussels (64 cases, 6 deaths) Clams (12 cases, 2 deaths)
1943	20	4	Del Norte, Humboldt	Mussels
1944	12	2	San Mateo, Santa Cruz	Mussels
1946	3	1	San Mateo	Mussels
1947	1	0	San Mateo	Clams
1948	3	1	San Mateo	Mussels
1954	5	0	Sonoma, Marin	Mussels
1962	4	0	Marin	Oysters
1969	15	0	Humboldt, Mendocino	Mussels
1971	15	0	Humboldt, San Francisco, San Mateo	Mussels
1980	98	2	Sonoma, Marin	Mussels (36 cases, 1 death) Oysters (61 cases, 0 deaths) Scallops (1 case, 1 death)
1989	2	0	Mendocino	Mussels
TOTAL	510	32		

[1] Probable source of the shellfish causing the PSP illness.

The early quarantines applied to designated sections of the coast, initially from Monterey to Del Norte Counties. In 1936, the southern boundary was extended to include Ventura County, following the occurrence of three cases, including two deaths, from mussels collected in that county in May of that year. The following year, Los Angeles County also was included. The early quarantines specifically excluded San Francisco Bay. It was not until 1942 that San Francisco Bay and the entire coast of California, from Oregon to Mexico, were included in the quarantine. Also in that year, while the quarantine remained limited to mussels, it included an advisory about discarding the dark meat, or viscera, of clams before eating them.

TABLE 3.

California's PSP cases according to type of shellfish, 1927–89.

	Cases	Deaths
Mussels	422	25
Clams	21	5
Oysters	65	0
Scallops	1	1
Unknown	1	1
TOTAL	510	32

The annual quarantine order is a preventive measure and is routinely issued each year. Since PSP toxin levels can increase rapidly and unpredictably, especially in mussels, and since the approximately 1,000-mile length of California's coastline makes it virtually impossible to adequately sample for PSP activity with available resources, CDHS believes the order is well justified. The annual quarantine is restricted to mussels because of their common occurrence along the open coast where they are quickly exposed to oceanic blooms of toxic dinoflagellates, and because mussels tend to acquire the toxin more rapidly and to concentrate it at higher levels than other kinds of shellfish. Also, as noted in Table 3, mussels have been responsible for the majority of California PSP cases (83 percent) and deaths (78 percent).

The annual quarantine is supplemented by an ongoing coastal shellfish sampling program. Information on PSP levels obtained from this program is used to modify or expand the quarantine, as necessary–i.e., either the time period or the kinds of mollusks covered.

The quarantine applies only to sport-harvested mussels. Mussels and all other bivalves grown and harvested by licensed commercial operators in California are subject to a separate PSP testing program, as described below. Commercial shellfish entering California from other states are subject to similar controls.

3. *Coastal Shellfish Monitoring*

Although blooms of *P. catenella* in California's coastal waters generally occur during the warmer months of the year, there is insufficient understanding of the environmental and biological factors affecting *P. catenella* populations to adequately predict bloom occurrences (Yentsch 1984). Available information only confirms that toxic blooms along the California coast are very irregular, both with respect to place and time. Because their appearance cannot now be predicted, nor their presence detected by other means, California, like most other states with PSP problems, relies on a coastal shellfish monitoring program to detect bloom developments (Nishitani and Chew 1988, Chiang 1988, Shumway et al. 1988).

Figures 1 and 2 show the locations of the 15 coastal counties of California, the principal commercial shellfish harvesting areas, and selected coastal sampling sites referred to in this report.

During the period 1927–36, a shellfish sampling program using the newly developed mouse bioassay was conducted by the G. W. Hooper Foundation of the University of California, San Francisco, as part of the pioneering studies of PSP. The results of this sampling effort were described by Sommer and Meyer (1937).

Records of shellfish testing for PSP during the 1940s and 1950s are incomplete and difficult to interpret. It appears that during these two decades little or no PSP testing was performed in a number of years. It was not until 1962 that the coastal monitoring program became an ongoing annual activity. Similarly, it was not until 1962 that PSP levels were expressed in micrograms (μg) of toxin per 100 grams of shellfish tissue, rather than the earlier "liver units" and "mouse units." For these reasons, this report

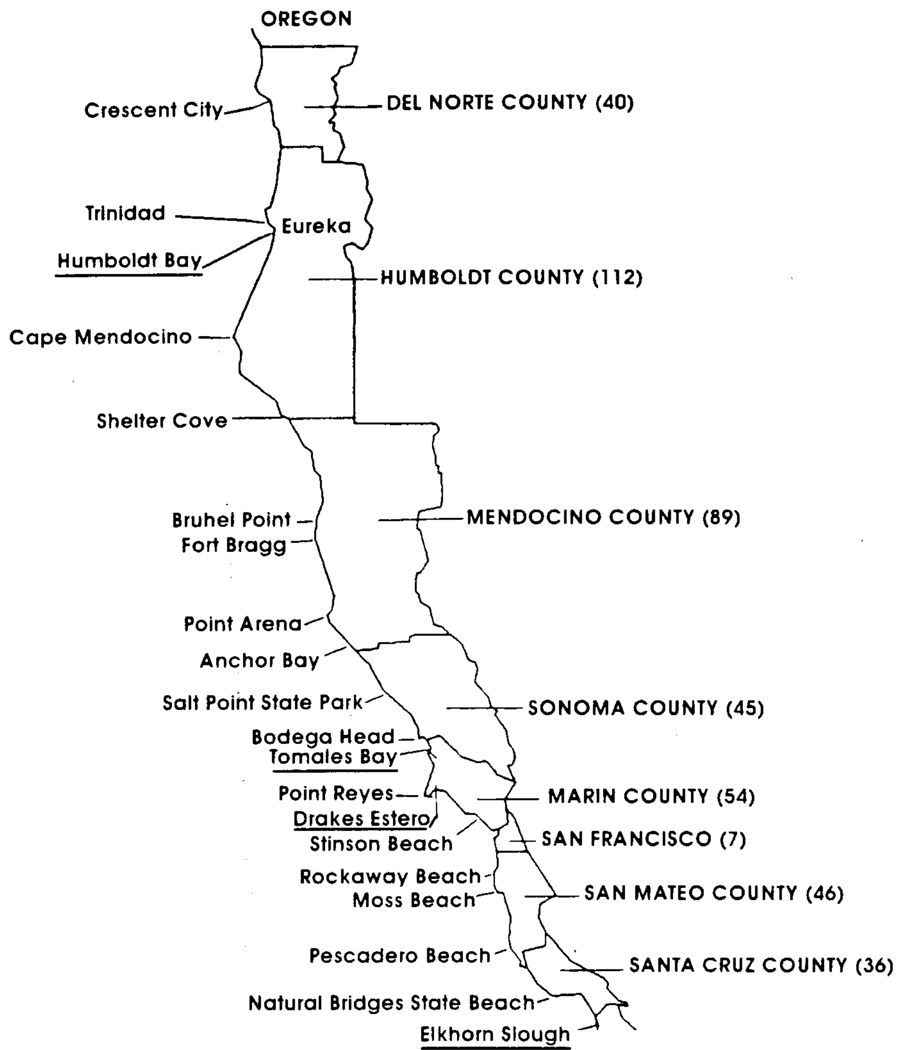

Figure 1. Central and Northern California coastal counties from Del Norte to Santa Cruz, with coastal mileages (in parentheses), commercial shellfish growing areas (underlined), and selected geographic locations and sampling sites.

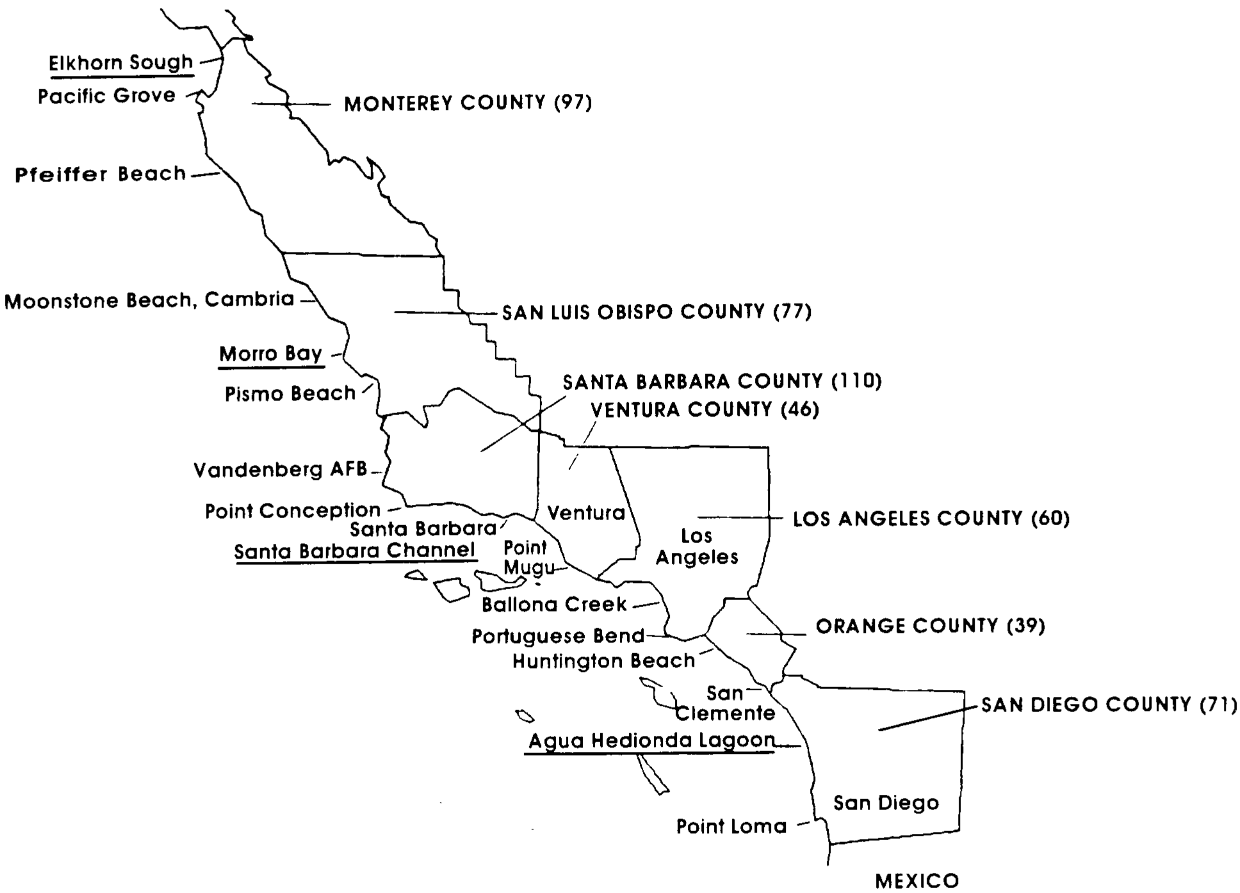

Figure 2. Central and Southern California coastal counties from Monterey to San Diego, with coastal mileages (in parentheses), commercial shellfish growing areas (underlined), and selected geographic locations and sampling sites.

summarizes and focuses primarily on the findings of the shellfish sampling program that began in 1962.

The monitoring program began as an informal agreement between the CDHS and several coastal county health departments. The latter would collect and submit shellfish samples to CDHS for PSP testing; CDHS would then analyze the samples and report the results back to the counties. The coastal counties did not all become a part of the monitoring effort at the same time. The program first involved the northern counties, and it later grew to include southern counties.

As the CDHS PSP Prevention Program evolved, a sampling protocol was formulated which suggested that each county select two sampling locations, and that a sample from each site be submitted at biweekly intervals during the quarantine period and at monthly intervals during the non-quarantine period. The guideline, if followed, would have provided for relatively regular and uniform geographic coverage of the coast. However, for various reasons, some coastal county health departments have not been able to participate in the sampling effort as fully as initially anticipated. As a result, the number of samples submitted by these local agencies varies widely, a fact which contributes to the uneven sampling patterns which have characterized the monitoring program, especially in its early years. The total number of samples submitted for PSP analyses each year since 1962 is shown in Figure 3.

Monitoring by the coastal counties is augmented in some areas by samples collected by CDHS, the California Department of Fish and Game (CDFG), the University of California, Vandenberg Air Force Base, and various other program participants. In addition, samples are submitted by commercial shellfish harvesters as part of their permit requirements.

The number of samples submitted by various program participants during each of the past five years is shown in Table 4. The average number of samples submitted annually from each of the 15 coastal counties during the same time period is shown in Figure 4. The wide range in numbers of samples submitted from each county reflects, in part, the length of the coastline, the involvement of local health agencies, the presence or absence of commercial shellfishing operations, and the size and nature of shellfish resource. Also, some areas, for example parts of Monterey, Mendocino, and Humboldt counties, are relatively remote and inaccessible for routine sampling activities.

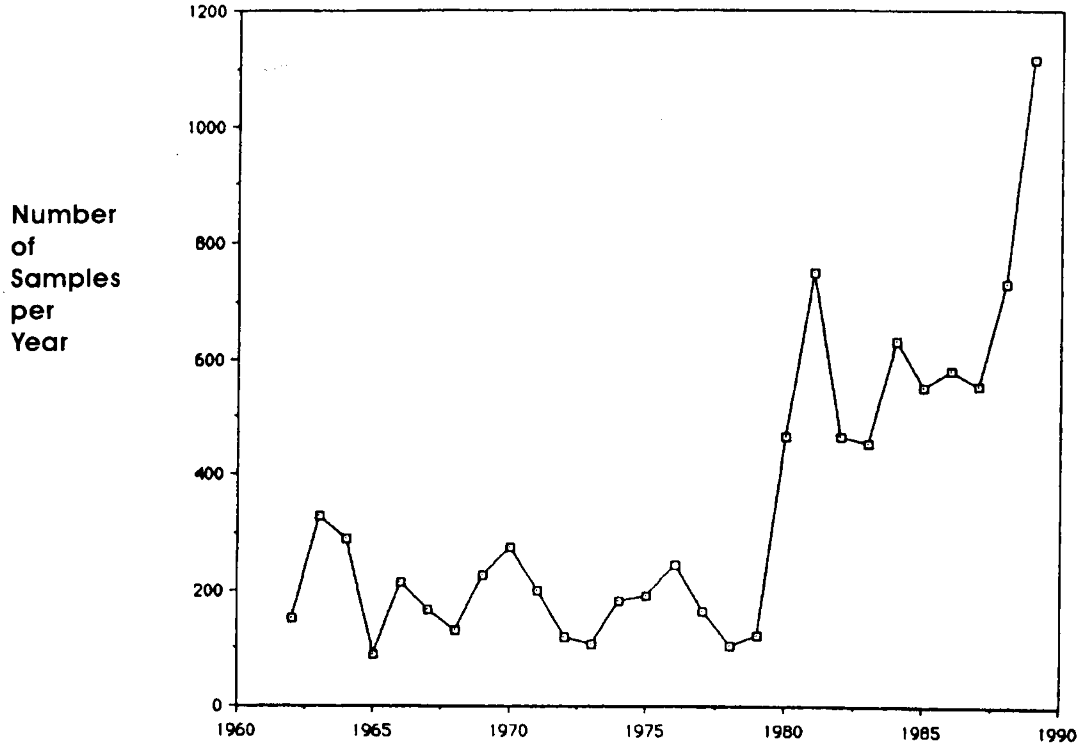

Figure 3. Total number of shellfish samples submitted annually to the California Department of Health Services for paralytic shellfish poison (PSP) analysis during the period 1962–1989

Because toxic dinoflagellate blooms in California begin in ocean waters and secondarily are carried into bays and estuaries through currents and tidal action, shellfish toxin levels in bays and estuaries generally are lower than those in adjacent open-coastal locations. It follows, therefore, that samples from the open coast have greater value in an early warning system for toxic bloom detection than do those from protected waters. This is why sampling has been targeted to open coastal locations.

In 1988, the CDHS adopted a sampling technique in which mussels or other shellfish are placed in retrievable nylon mesh bags hung into ocean waters from piers or other suitable structures. These so-called sentinel stations offer safety advantages to the sampler in that the bags can be retrieved at any time independent of the need for low tides or suitable weather and surf conditions. Use of this procedure is limited because most of the open coast lacks piers or other structures overhanging the water from which bags can be hung.

Primary sentinel stations are located at Trinidad, Humboldt County; the U.S. Coast Guard Station in Humboldt Bay; Lawson's Landing in Tomales Bay; and at the Old Coast Guard Station near Chimney Rock, Drakes Bay.

4. *Shellfish Sampling from Commercial Harvesting Areas*

The coastal shellfish monitoring program was expanded in 1981 when CDHS required that commercial shellfish growers submit samples from their shellfishing beds at weekly intervals, year-round, during all harvesting periods. This requirement was imposed as a consequence of a PSP outbreak in 1980 during which 61 people became ill from eating commercially grown oysters. Even before 1981,

TABLE 4.

Number of PSP samples submitted annually during the period 1985–1989 by commercial shellfish growers, government agencies, research institutions, and other program participants.

	1985	1986	1987	1988	1989
Commercial Shellfish Growers	249	295	298	364	550
Local Health Departments	183	176	170	191	171
Department of Health Services	—	8	6	82	230
Department of Fish and Game	11	8	8	11	50
U.C. Bodega Marine Laboratory	22	23	15	27	29
Vandenberg Air Force Base	25	24	25	30	28
Golden Gate National Recreational Area	—	—	4	7	18
Other Program Participants[1]	63	49	29	20	46
Total	553	583	555	732	1,122

[1] Other program participants include Lawson's Landing Resort, Tomales Bay, Marin County; Point Reyes Bird Observatory, Marin County; Fitzgerald Marine Reserve, San Mateo County; Orange County Marine Institute; California Department of Parks and Recreation; U.S. Naval Air Station, Point Mugu, Ventura County; and Neushul Mariculture, Santa Barbara County.

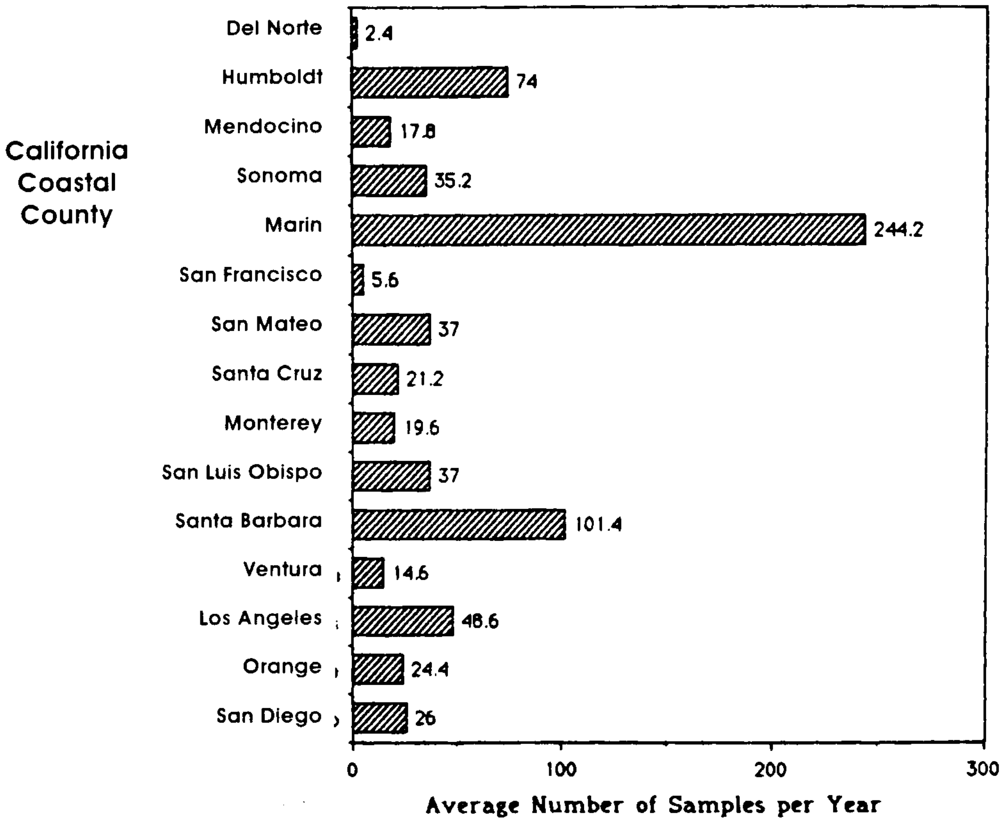

Figure 4. Average number of samples submitted for paralytic shellfish poison (PSP) analysis from each California coastal county during the period 1985–1989

however, samples commonly were sent to CDHS for testing by shellfish growers, particularly from Humboldt Bay, Tomales Bay, and Drakes Estero. Although not mandatory, sampling was done voluntarily to ensure product safety. In recent years, about one-half of all samples received for PSP testing have been submitted by commercial shellfishing companies (Table 4).

Year-round testing of commercially grown shellfish not only helps to protect the consumer, but is essential for the development and economic success of the State's expanding shellfishing industry. PSP outbreaks, such as occurred in New England in 1972 and California in 1980, can have protean untoward impacts on shellfish markets, as well as on the general fisheries industry (Jensen 1975, Conte 1984). An overview of the economic effects of PSP and costs of PSP prevention programs on the North American shellfishing industry is given by Lutz and Incze (1979). The cost of the California PSP Prevention Program is borne, in part by the State's general fund as a public health protection program, and, in part, by license fees paid to the Department of Fish and Game.

5. *Public Education*

The public education effort is directed primarily toward sport shellfish harvesters and is closely linked to the annual mussel quarantine. Opening of the annual quarantine period is widely announced in the media by means of CDHS press advisories. These news releases contain a statement of the quarantine, the reasons for it, and background information on PSP. Extensions of the quarantine beyond the normal closing date, inclusion of shellfish other than mussels, and all other emergency actions are also announced by press advisories and public notices.

CDHS keeps all local health agencies, the CDFG, the California Department of Parks and Recreation, and other relevant entities informed about coastal PSP activity and the status of all quarantines so they can assist in enforcement and public education activities.

As part of the public information effort, quarantine warning signs are prepared and posted in shellfishing areas by local health departments. Since 1980, in addition to being printed in English and Spanish, signs also have been printed in Vietnamese, Cambodian, Laotian, Ilocano, and Tagalog. Special effort is made to reach recent immigrants from the Philippines and Southeast Asia, since these groups have accounted for a disproportionate number of PSP cases in California in recent outbreaks. For example, in 1980, 13 of 36 cases due to the consumption of mussels were Filipinos (Sharpe 1981). Also, of the 15 reported cases in each of the outbreaks of 1969 and 1971, 12 in each were Filipinos. The high incidence among Filipinos, and to a lesser extent among immigrants from Southeast Asian countries, may be explained by a cultural dietary penchant for mussels and other shellfish and unfamiliarity with PSP, which rarely occurs in that part of the world.

In addition to CDHS public education efforts, the University of California Sea Grant Extension Program publishes an informational bulletin on PSP for the general public (Price 1989).

FINDINGS OF THE COASTAL MONITORING PROGRAM

In spite of the high level of PSP activity along the California coast, there has been almost no academic research on this problem in the State since the early studies by Meyer, Sommer, and their co-workers in the late 1920s and 1930s. Instead, recent advances in the understanding of this phenomenon in California have come primarily from the CDHS coastal shellfish monitoring program and other health protection activities.

Although, as already noted, the monitoring effort has been somewhat sporadic since being initiated in 1962, the sampling data from recent years are yielding important new information on the frequency, intensity, seasonal occurrence, geographic distribution, dimensions, and other related aspects of toxic dinoflagellate blooms and toxification of shellfish along the California coast. Eventually, these data may permit correlation of toxic blooms with climatic and hydrographic conditions which, in turn, might lead to prediction capabilities. Until then, however, the monitoring data are providing useful clues concerning the ecology and dynamics of toxic blooms–information essential in developing optimal sampling strategies, predicting the course of bloom expansion and decline, and, in general, providing a more effective public health protection program. Some of these findings are described below.

Frequency of PSP Blooms in California

A "bloom" may be defined as a discrete proliferation of toxic dinoflagellates which causes PSP toxin levels in exposed shellfish to rise above some detectable level. Because a bloom is detected indirectly (i.e., by measuring toxin in shellfish), our knowledge of bloom frequencies is limited by the number and distribution of sampling sites along the coast and the frequency of sampling. Although limited, data available since 1962 permit an estimate of this aspect of bloom occurrences.

A review of sampling data from California reveals that for most years samples measuring 80 μg/100 g (the federal FDA alert level) or more are very common, occurring too frequently to provide meaningful information on toxic bloom frequencies. For that reason, CDHS has operationally defined a bloom as occurring at levels of 160 μg/100 g or more. Also, a discrete bloom is defined as one which is separate from other similar events, both in location and time of occurrence. In some years, because of spatial and temporal gaps in sampling data, it is not possible to determine if elevated toxin levels in coastal shellfish are the result of a single large bloom or of smaller discrete blooms. Table 5 shows the number of discrete toxic blooms, as defined here, detected along the California coast from 1962 through 1989, along with the location of the bloom, the months of occurrence, and the highest toxin level obtained for each county involved in the bloom.

It is clear from the data in Table 5 that toxic dinoflagellate blooms commonly occur off the California coast, having recorded 34 distinct blooms between January 1962 and December 1989, inclusive. In only 6 of 28 years was no bloom identified. In 10 years, 2 or more toxic blooms were detected. However, because of limited sampling, especially in the years prior to 1980, it is likely that many blooms went undetected.

Intensity of PSP Blooms in California

Sampling data (Table 5) have shown that toxic dinoflagellate blooms not only are relatively common along the California coast, but that shellfish toxicity also frequently reaches levels that could cause serious health problems if it were consumed. Table 5 shows that of 34 identified blooms, 31 (91 percent) yielded shellfish with toxin levels of 200 μg/100 g or higher; 17 (50 percent) yielded samples of 500 μg/100 g or higher; and 8 (24 percent) yielded specimens having levels of 2,000 μg/100 g or higher.

Bloom intensities also may be described by the highest shellfish toxin levels encountered. As shown in Table 6, the federal alert level of 80 μg/100 g has been exceeded in one or more locations in 26 of the past 28 years (93 percent). Levels have equaled or exceeded 200 μg/100 g in 21 of the past 28 years (75 percent), 500 μg/100 g in 14 years (50 percent), and 2,000 μg/100 g in 8 years (29 percent). It is also of interest that levels have exceeded 1,000 μg/100 g in 6 of the past 10 years. The reason for detecting higher toxin levels during recent years is unclear. It is possible that this is an artifact of more intense sampling, rather than of any real increase in high-level toxic blooms.

Seasonal Occurrence of PSP Blooms in California

As previously noted, the annual mussel quarantine period evolved during the 1930s to encompass those months having the highest PSP risks. The period chosen in 1942, May 1 through October 31, has included over 99 percent of all reported PSP cases in California since 1927. The only exceptions were two cases in March 1931, and one case (fatal) in April 1932 (Sharpe 1981). The two largest PSP outbreaks in California, in 1927 and 1980, began during the month of July. As can be seen from Table 7, the overwhelming majority of PSP cases from other years (94 percent) have occurred during the 4-month period June through September, with July being the peak single month (58 percent) (Sommer and Meyer 1937; Sharpe 1981). June, July, and August also lead in the number of PSP

TABLE 5.

Toxic dinoflagellate blooms along the California coast, 1962–89.[a]

Year	Counties Involved	Highest Toxin Level[1]	Location	Date
1962	Sonoma	1,200	Bodega Bay	08/24/62
	Marin	1,920	Drakes Estero	07/28/62
1962	Mendocino	428	Mendocino Coast	10/25/62
1963	Marin	400	Drakes Estero	07/18/63
1965	Marin	340	Drakes Estero	08/30/65
1966	Marin	360	Drakes Estero	01/28/66
1966	Mendocino	1,600	Mendocino Coast	08/25/66
	Marin	250	Drakes Estero	07/26/66
1967	Mendocino	240	6m. N. Ft. Bragg	08/31/67
1968	Sonoma	170	Horseshoe Cove	07/10/68
1968	Sonoma	200	Horseshoe Cave	09/06/68
1969	Humboldt	2,300	Shelter Cove	09/23/69
	Mendocino	1,900	Fort Bragg	10/01/69
	Sonoma	170	Salt Point	10/01/69
1970	Sonoma	240	Ocean Cove	02/18/70
1970	Sonoma	210	Mussel Point	06/24/70
	Marin	280	Stinson Beach	06/24/70
	San Francisco	760	Lands End	07/21/70
	San Mateo	2,800	Graywhale Cove	07/20/70
1971	Humboldt	850	Trinidad	09/09/71
	Sonoma	510	Bodega Head	08/11/71
	Marin	290	Drakes Estero	07/28/71
	San Francisco	3,200	Lands End	08/10/71
	San Mateo	6,000	Moss Beach	08/05/71
	Santa Cruz	340	Natural Bridges	08/10/71
1973	Humboldt	162	College Cove	07/18/73
1975	Mendocino	498	Mussel Point	09/10/75
1976	Sonoma	200	Sea Ranch	03/11/76
	Marin	240	Stinson Beach	03/12/76
1976	Sonoma	280	Bodega Head	07/30/76 and 08/10/76
1980	Ventura	309	Bass Rock	05/19/80
1980	Sonoma	14,000	Duncan's Landing	07/26/80
	Marin	16,000	Tomales Bay	07/29/80
	San Francisco	500	Phelan Beach	07/31/80
1980	Mendocino	330	Mussel Rock	11/18/80
1981	Sonoma	2,200	Schoolhouse Beach	10/13/81
	Marin	870	Dillon Beach	10/09/81
1982	Mendocino	220	Bell Point	09/02/82
	Sonoma	640	Schoolhouse Beach	09/03/82
	Marin	690	Rodeo Cove	08/18/82
	San Mateo	470	Graywhale Cove	08/27/82
1983	San Francisco	210	Baker Beach	07/26/83
	San Mateo	240	Pillar Point	07/14/83
1984	Sonoma	190	Mussel Point	03/11/84
	Marin	4,000	Chimney Rock	03/08/84
	San Francisco	520	Yerba Buena Island	03/16/84
	San Mateo	670	Moss Beach	03/14/84
	Santa Cruz	170	Natural Bridges	03/14/84

TABLE 5.
continued

Year	Counties Involved	Highest Toxin Level[1]	Location	Date
1984	Mendocino	1,520	Bruhel Point	08/29/84
	Sonoma	180	Bodega Head	08/28/84
	Marin	680	Kehoe Beach	08/27/74
1985	San Luis Obispo	340	Moonstone Beach	04/08/85
	Santa Barbara	4,100	Santa Barbara Channel	04/10/85
	Ventura	300	Mobil Pier	04/05/85
1986	Marin	300	Drakes Estero	04/09/86
1986	Marin	1,900	Drakes Estero	06/18/86
	Marin	1,900	Rodeo Cove	06/27/86
	San Francisco	400	China Beach	06/23/86
	San Mateo	390	Graywhale Cove	06/24/86
1987	Marin	180	Chimney Rock	05/19/87
1987	Sonoma	500	Mussel Point	08/11/87
	Marin	440	Drakes Estero	07/24/87
	San Mateo	270	Point San Pedro	07/28/87
1988	Marin	810	Chimney Rock	08/01/88
	San Mateo	330	Ano Nuevo State Beach	07/14/88
1989	Marin	1,800	Chimney Rock	01/10/89
1989	Humboldt	14,000	Humboldt Bay	09/18/89
	Mendocino	6,300	Anchor Bay	09/17/89
	Sonoma	5,500	Salt Point St. Park	09/24/89
	Marin	1,800	Tomales Bay	09/07/89
	Marin	1,800	Point Reyes N.S.	09/19/89
	San Mateo	800	Moss Beach	08/20/89
	Santa Cruz	930	Near San Mateo Co. Line	08/18/89
1989	San Luis Obispo	1,600	Cayucos	12/13/89

[1] In micrograms toxin per 100 g of shellfish meat. All samples are mussels except those from Drakes Estero, Marin County, in 1962, 1963, 1965, 1966 (2 samples), and 1971, which were oysters.
[a] From CDHS Shellfish Monitoring Program; no blooms detected in years not listed. Only samples of 160 ug/100 g or greater are included. Clam samples are excluded.

deaths (84 percent) (Table 7), and 31 of the deaths (97 percent) have occurred during the May–October quarantine period.

Although the mussel quarantine covers that part of the year during which the vast majority of PSP cases have occurred, the CDHS sampling program has revealed that toxic dinoflagellate blooms are not limited to only the warmer months of the year. Toxic blooms have caused numerous extensions of the quarantine period beyond October 31, and early-season quarantines prior to May 1 have not been unusual in recent years.

Table 8 shows the month of highest reported toxin levels for the 34 dinoflagellate blooms identified in Table 5. As expected, July and August lead in the number of bloom peaks (74 percent). Also, it is interesting that while a peak toxin level has been detected only one time during June, this month leads all, except July, in the number of reported PSP illnesses (Table 7).

The occurrence of toxic blooms during nonquarantine months, although less frequent than those during the May–October period, underscores the need for a year-round coastal monitoring program and mandatory weekly sampling requirements for all commercial harvesters. Obviously, the occurrence of toxic blooms during nonquarantine months causes special public health concerns. Such occurrences must be detected and promptly acted upon.

Coastal shellfish toxicity in the three southernmost California counties (i.e., Los Angeles, Orange, and San Diego) has not exceeded the 160 μg/100 g level since monitoring began. However, if one tabulates minor elevations in toxicity (80 μg and above) from this part of the State, no seasonal patterns emerge. At least as many such events occurred during the nonquarantine period as during the quarantine period (Table 9). It seems important, therefore, that these counties maintain a uniform sampling effort throughout the year. In this area, it appears as though a toxic bloom could occur during any season of the year.

In the area immediately north of Los Angeles County,

TABLE 6.

Highest PSP toxin levels detected in the California shellfish monitoring program by year, 1962–89.

Year	Month	Highest Level[1]	County
1962	July	1,920[a]	Marin
1963	July	400[a]	Marin
1964	July	93[b]	Marin
1965	August	340[a]	Marin
1966	August	1,600	Mendocino
1967	August	240	Mendocino
1968	April	270[b]	Sonoma
1969	September	2,300	Humboldt
1970	July	2,800	San Mateo
1971	August	6,000	San Mateo
1972	March	131	Los Angeles
1973	July	162	Humboldt
1974	May	92	Orange
1975	September	498	Mendocino
1976	July, August	280	Sonoma
1977	December	66	Ventura
1978	May	92	Santa Barbara
1979	September	68	San Luis Obispo
1980	July	16,000	Marin
1981	October	2,200	Sonoma
1982	August	690	Marin
1983	July	240	San Mateo
1984	March	4,000	Marin
1985	April	4,100	Santa Barbara
1986	June	1,900	Marin
1987	August	500	Sonoma
1988	August	810	Marin
1989	September	14,000[c]	Humboldt
1989	September	6,300[d]	Mendocino

[1] In micrograms of toxin per 100 grams of shellfish meat. Samples are mussels unless otherwise indicated.
[a] Oysters.
[b] Clams.
[c] Sentinel sea mussels.
[d] Wild sea mussels.

toxic blooms appear to be early season events. For example, the two reported blooms from Ventura County in 1980 and 1985 occurred during April and May (Table 5). Similarly, the intense and, to date, only toxic bloom recorded in Santa Barbara County occurred during March and April 1985 (Table 5). Also of note is the unusual bloom in San Luis Obispo County which occurred during December 1989 (Table 5).

Geographic Distribution of Toxic Dinoflagellates Along the California Coast

The California coast extends in straight-line measurements about 930 miles (1,497 kilometers) from Oregon to Mexico, a distance comparable to that from northern Maine to Virginia, although the actual coastline, including all bays and inlets, measures approximately 1,100 miles. Given this length, it is not surprising that toxic bloom activity shows considerable geographic differences in both frequency of occurrence and intensity.

In general, Northern California experiences significantly more PSP activity than does Southern California. Toxic bloom activity, however, does not increase linearly as one moves north, but rather tends to be concentrated in the north-central part of the State, especially in the area immediately north and south of San Francisco Bay. As shown in Table 10, Marin County has been the most frequent center of bloom activity, followed by Sonoma and Mendocino Counties. The five counties having the most frequent occurrence of toxic blooms are Mendocino, Sonoma, Marin, San Francisco, and San Mateo (Table 10). Collectively,

TABLE 7.

Incidence of PSP illnesses by month, California, 1927–89.

Month	Cases		Deaths	
	Number	(%)	Number	(%)
January	0	(0.0)	0	(0.0)
February	0	(0.0)	0	(0.0)
March	2	(0.4)	0	(0.0)
April	1	(0.2)	1	(3.1)
May	7	(1.4)	2	(6.3)
June	82	(16.1)	8	(25.0)
July	293	(57.7)	10	(31.3)
August	67	(13.2)	9	(28.1)
September	36	(7.1)	0	(0.0)
October	20	(3.9)	2	(6.3)
November	0	(0.0)	0	(0.0)
December	0	(0.0)	0	(0.0)
TOTAL	508[a]		32	

[a] Month of occurrence of two PSP illnesses in 1937, Santa Cruz County, is not available.

TABLE 8.

Month of highest reported PSP toxin level in coastal shellfish during each of 34 dinoflagellate blooms in California, 1962–89.

Month	Number of Bloom Peaks[1]
January	2
February	1
March	2
April	2
May	2
June	1
July	8
August	9
September	4
October	2
November	1
December	1
TOTAL	35

[1] A 1976 bloom had equal peak levels in both July and August.

TABLE 9.

Mussel samples with PSP toxin levels of 80 or more μg/100 g of shellfish meat from southern California, 1970–88.

Year	Date	Location	County	Toxin Level[1]
1970	May 28	Venice	Los Angeles	100
1971	June 7	Venice	Los Angeles	91
1972	March 9	Portuguese Bend	Los Angeles	131
1974	May 9	Corona Del Mar	Orange	92
1976	January 15	Huntington Beach	Orange	95
1976	January 15	Newport Beach	Orange	88
1980	April 14	San Clemente	Orange	111
1983	September 12	Portuguese Bend	Los Angeles	110
1984	May 17	Huntington Beach	Orange	100
1984	May 17	San Clemente	Orange	110
1985	January 6	Marina Del Rey	Los Angeles	125
1985	January 17	Portuguese Bend	Los Angeles	94
1985	March 22	La Jolla	San Diego	150
1985	April 2	Huntington Beach	Orange	91
1986	March 24	Portuguese Bend	Los Angeles	86
1987	April 7	Portuguese Bend	Los Angeles	96
1988	March 14	Portuguese Bend	Los Angeles	83

[1] In micrograms toxin per 100 g of shellfish meat.

these 5 counties have been involved in 83 percent of the 34 blooms recorded since 1962.

Table 11 shows the highest levels of PSP toxin reported from each of the 15 coastal counties during the period 1962–89, along with the number of years in which each county has been a part of the monitoring effort. As already noted, the monitoring program first involved the northern counties, and later those to the south. Del Norte County is an exception in that very few samples have been submitted from that area–a fact which explains the low PSP level in Table 11. The maximum levels reported reflect the higher overall PSP activity in Northern California.

Plots of the highest toxin levels encountered during each year of the monitoring program for each county permits a comparison of general PSP activity in discrete coastal areas. Such plots also show that toxic blooms sometimes occur in areas with little or no prior history of such occurrences. For example, as shown in Figure 5, the 1985 bloom event in Santa Barbara followed 15 years of monitoring (1970–1984) during which period the highest recorded level of PSP toxin was only 97 μg/100 g.

Similarly, the unusual bloom in December 1989, in San Luis Obispo County, occurred in an area of low PSP activity, as shown in Figure 6. Marin and Sonoma counties, by contrast, have more active histories of toxic blooms (Figures 7 and 8).

These records, although showing only the single highest toxin level per year, allow one to visualize the unpredictable nature of blooms in California. In addition, over a period of years, these types of data might reveal cycles of toxic bloom activity and long-term trends in the frequency and intensity of blooms along the California coast. Also,

TABLE 10.

Counties affected in 34 discrete toxic blooms, 1962–89.

County	Number of Occurrences: Bloom Center[1]	Bloom Involvement[2]
Del Norte	0	0
Humboldt	3	4
Mendocino	6	9
Sonoma	6	16
Marin	13	20
San Francisco	0	6
San Mateo	3	8
Santa Cruz	0	3
Monterey	0	0
San Luis Obispo	1	2
Santa Barbara	1	1
Ventura	1	2
Los Angeles	0	0
Orange	0	0
San Diego	0	0
Total	34	

[1] Number of times each county has had the highest reported level of PSP toxin in any given toxic bloom.
[2] Number of times each county has been included in a discrete bloom, as defined in text. Counties without sampling data during bloom periods are not included, and, thus, this may understate their actual occurrence.

TABLE 11.

Highest PSP toxin level reported by county, 1962–89.

County	Number of Years Monitored[1]	PSP Level[2]	Year
Del Norte	4	76	1981
Humboldt	28	14,000[a]	1989
Mendocino	26	6,300	1989
Sonoma	28	14,000	1980
Marin	28	16,000[b]	1980
San Francisco	28	3,200	1971
San Mateo	28	6,000	1971
Santa Cruz	27	340	1971
Monterey	23	150	1988
San Luis Obispo	25	1,600	1989
Santa Barbara	20	4,100[c]	1985
Ventura	17	309	1980
Los Angeles	19	131	1972
Orange	21	111	1980
San Diego	12	150	1985

[1] Number of years in which one or more samples were submitted for PSP testing.
[2] In micrograms toxin per 100 grams of shellfish meat. Samples are wild sea mussels unless otherwise noted.
[a] Sentinel sea mussels, Humboldt Bay.
[b] Bay mussels, Tomales Bay.
[c] Bay mussels, Santa Barbara Channel.

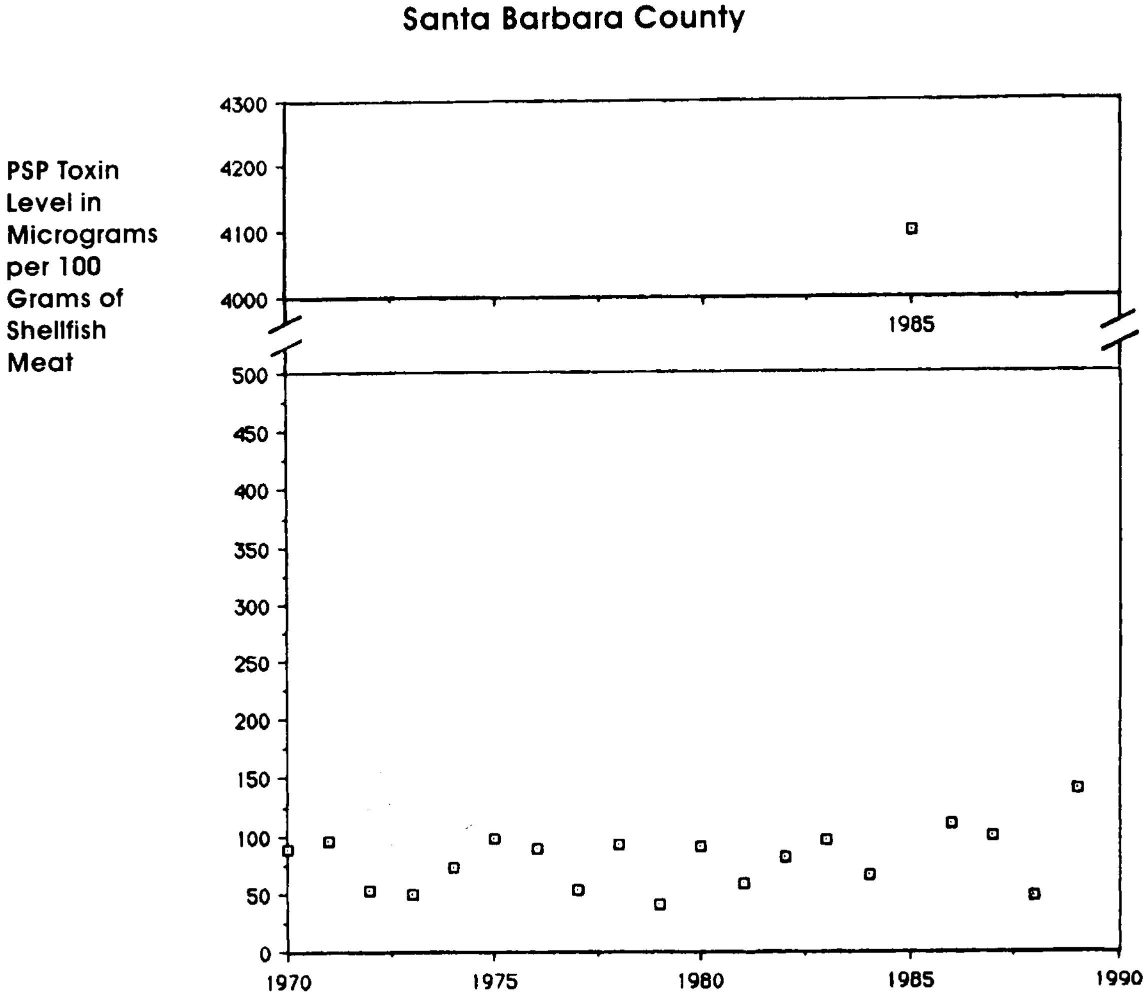

Figure 5. Highest level of PSP toxin per year reported from Santa Barbara County during the period 1970–1989

correlations between periods of high or low PSP activity and various climatic and oceanographic conditions, e.g., El Niño events, might be useful in development of bloom prediction capabilities.

Table 12 shows the distribution of PSP cases according to the source of the shellfish causing the illness. It is of interest that Santa Cruz and Monterey counties, although relatively quiet in terms of toxic dinoflagellate activity since the monitoring program began in 1962, have had a high number of PSP illnesses and deaths. All of these incidents occurred before 1962, suggesting that there may have been some changes in toxic bloom phenomena along the coast during the past 60 years.

Dimensions of Toxic Blooms in California

In their description of the 1927 PSP outbreak, Meyer et al. (1928) noted that human cases occurred at various locations along a 150-mile section of coast, i.e., from Wright's Beach in Sonoma County to Pacific Grove in Monterey County.‡ Also, in the 1927 outbreak, all cases occurred within the short time period July 14–17, indicating high levels of toxicity in shellfish along this entire section of coastline. Tests conducted at the time confirmed elevated toxin levels in mussels from numerous sites along the coast, as well as from the Farallone Islands 25 miles west of the coast. Studies of the 1927 outbreak provided the first indication that toxic blooms in California may encompass extensive sections of the coast.

Table 13 shows the northern and southern limits of ten major toxic blooms that occurred between 1962 and 1989. All of these blooms yielded toxin levels in shellfish in ex-

‡The text of the 1928 paper states that the southernmost PSP case was due to mussels collected at Pescadero, San Mateo County. However, a single case from Pacific Grove, Monterey County, is indicated on the map included as Figure 1. Because that case also is included in the later paper by Sommer and Meyer (1937), we have used Pacific Grove as the southern limit of the 1927 bloom.

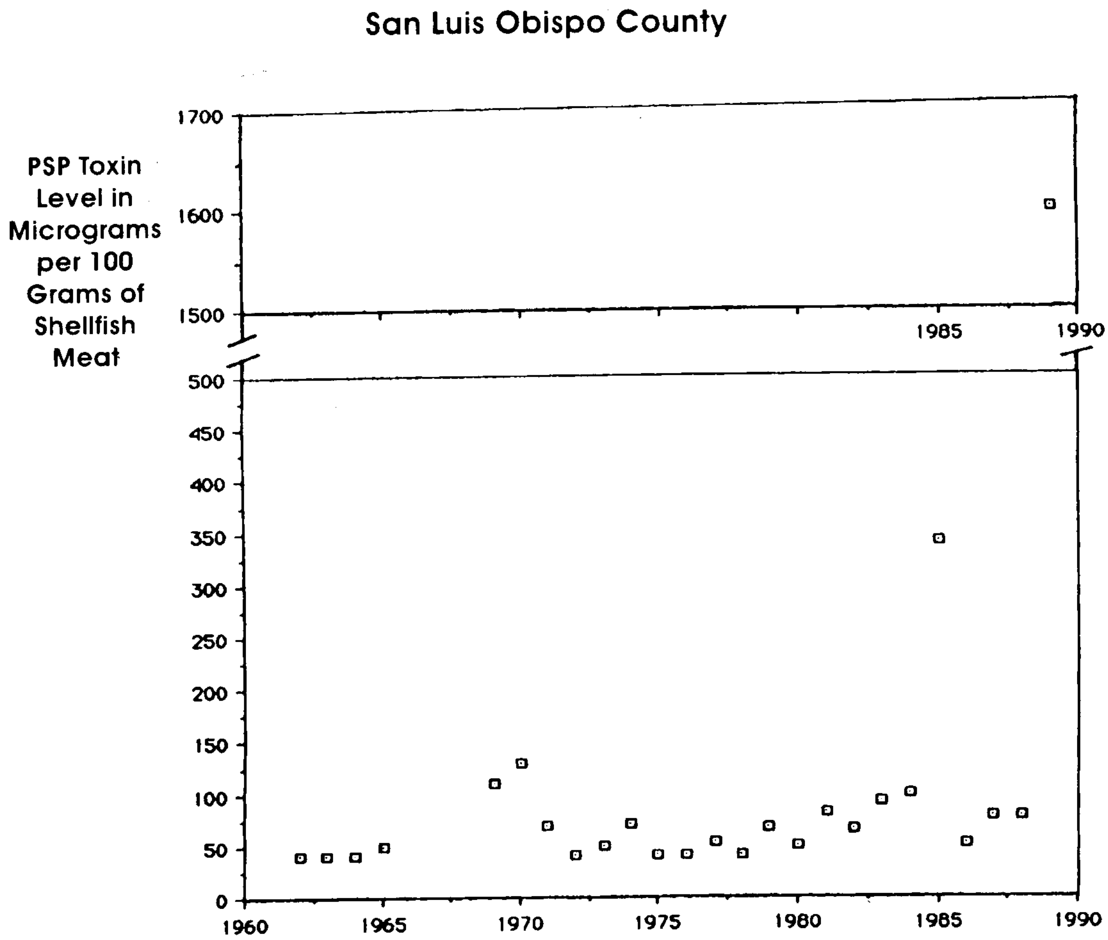

Figure 6. Highest level of PSP toxin per year reported from San Luis Obispo County during the period 1962–1989

cess of 1,000 µg/100 g. The geographic limits are based on the apparent northern and southern points at which toxin levels in shellfish equaled or exceeded 100 µg/100 g. Although the true dimensions are, of necessity, only estimated, information in Table 13 supports the observations of Meyer and Sommer (1937) that major blooms of toxic dinoflagellates along California's coast may extend for long distances.

Toxic Bloom Development

California data are insufficient to determine if major blooms grow from single locations, develop through coalescence of smaller discrete blooms (i.e., resulting from similar favorable conditions along the coast), or both. An alternative explanation is that toxic blooms develop offshore and move toward land in an already advanced stage, thereby causing rapid increases in shellfish toxicity. There is no specific evidence of this occurring from the California data, although this absence of data may be an artifact resulting from almost all sampling stations being located along the shoreline.

Better understanding of bloom development and expected variation in shellfish toxicity along sections of coastline is needed to design a more effective monitoring program. One needs to know the degree to which toxicity from one location provides information about toxin levels at nearby and distant locations along the coast. Clearly, the monitoring program should minimize the chance of blooms reaching dangerous levels without detection because sampling sites are too widely spaced.

California sampling data, to date, provide little information on variations in toxicity between adjacent sampling sites, especially during the early stages of bloom development. Nonetheless, the large size of toxic blooms which appear to be characteristic of California's coast suggest that detection should occur even with widely separated sampling sites (e.g., 10 to 20 miles) by the time a bloom has reached levels which pose a public health threat. However, as discussed later under "Dynamics of Shellfish Toxification," early detection of a developing bloom—before dangerous levels of toxin accumulate in coastal shellfish—requires an immediate increase in monitoring activities whenever low but rising levels of PSP are encountered.

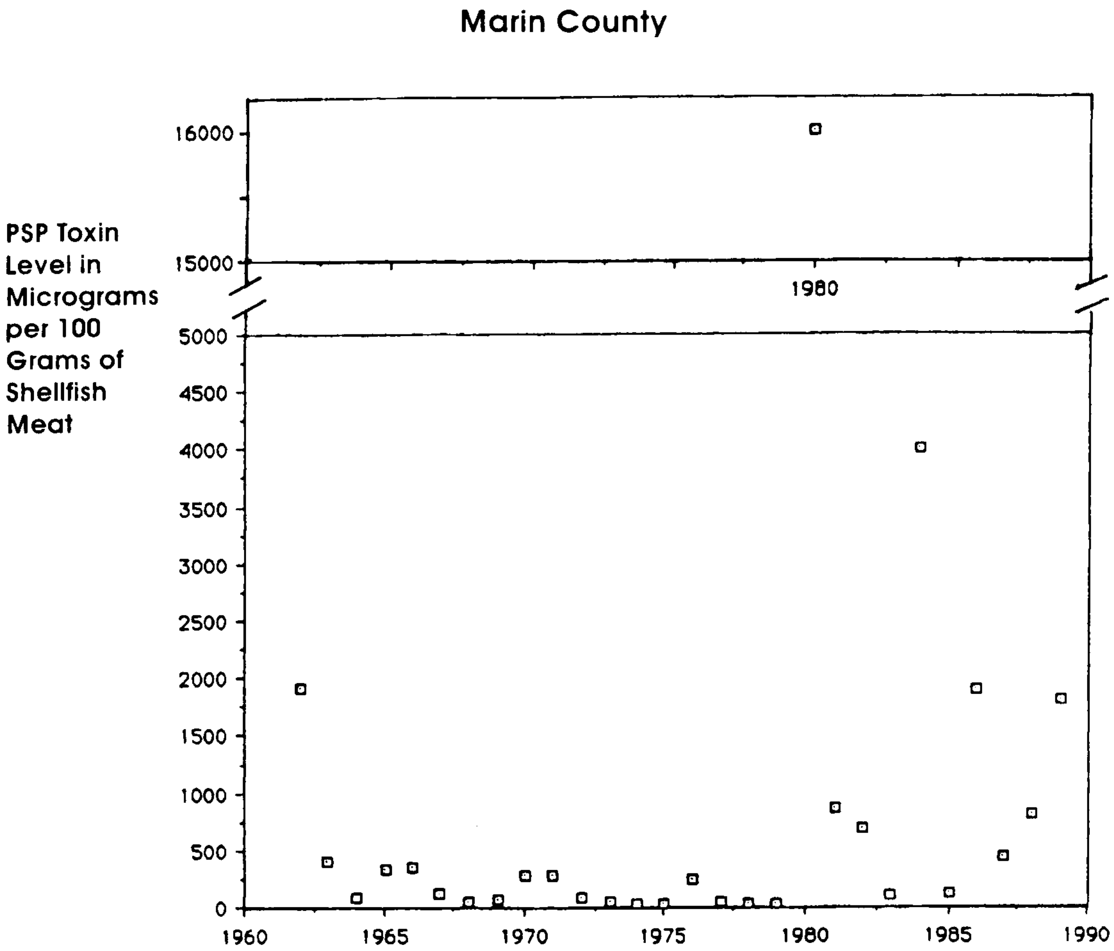

Figure 7. Highest level of PSP toxin per year reported from Marin County during the period 1962–1989

Duration of Toxic Blooms in California

Monitoring data associated with individual blooms not only provide information on bloom dimensions, but also on their duration. The latter, of course, is a measure of both the duration of the bloom itself and the retention time of toxin within the shellfish.

Because mussels and oysters appear to clear themselves of toxin fairly rapidly as a bloom fades, these are the best measures of bloom duration. Clams, and especially Washington clams, *Saxidomus nuttalli* (Conrad), may retain the toxin for considerable periods of time and, therefore, elevated toxin levels in clams do not necessarily indicate that a bloom is in progress.

Table 14 shows the apparent duration of the ten toxic blooms listed in Table 13 based on toxin levels in oysters and mussels. The duration of the 10 separate blooms ranged from 36 to 85 days, averaging 56 days. Of note, however, only samples with toxicity levels at or above the 100 μg level were used and, therefore, the time intervals are conservative. Also, in many cases, the amount of sampling decreased abruptly as the bloom subsided, so the time required for shellfish to drop below the 100 μg level was not always exactly determined.

Dynamics of Shellfish Toxification in California

Various investigators have noted that toxicity in bivalves can increase from safe to dangerous levels within a few days (McFarren et al. 1960). For example, Sommer and Meyer (1937) reported that toxicity in mussels from the Salmon Creek area of Sonoma County in 1932 showed a 100-fold increase in 12 days. Similarly, a study in Quebec, Canada, showed that toxicity of softshell clams (*Mya arenaria* Linnaeus) increased from 542 mouse units (~98 μg) to 26,180 mouse units (~4,712 μg) per 100 g within 6 days (Tennant et al. 1955). Further, studies in Maine showed that the blue mussel (*Mytilus edulis* Linnaeus) can increase in toxicity under optimum conditions at a rate of about 500 μg/100 g per day (Hurst and Gilfillan 1977). In the same study, the softshell clam (*Mya arenaria*) showed a maximum gain of 116 μg/100 g per day, with a daily average toxin gain of about 77 μg.

The rate of toxification is a critical factor in determining

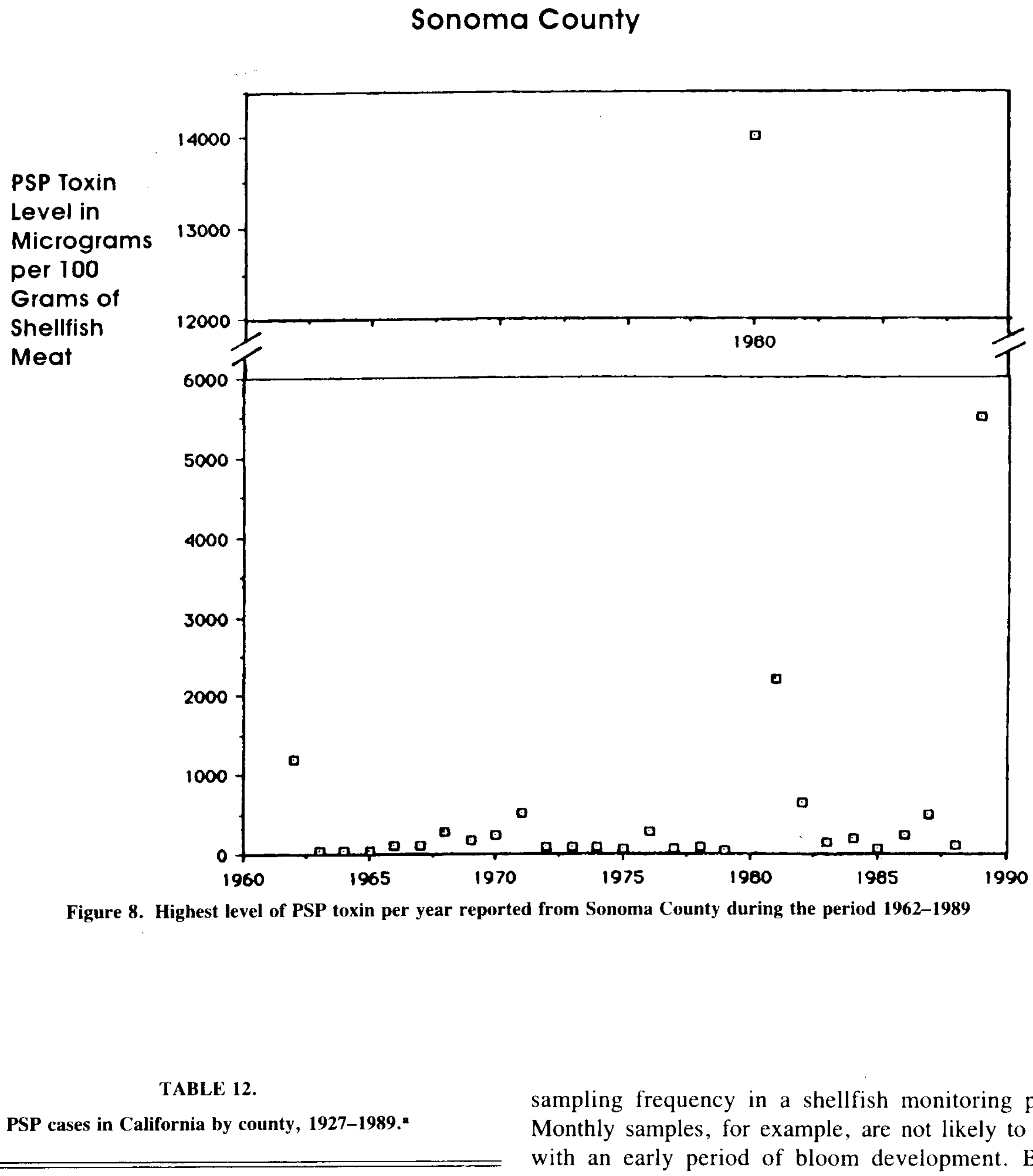

Figure 8. **Highest level of PSP toxin per year reported from Sonoma County during the period 1962–1989**

TABLE 12.

PSP cases in California by county, 1927–1989.[a]

County	Cases[1]	Deaths
Del Norte	9	0
Humboldt	23	4
Mendocino	15	0
Sonoma	84	7
Marin	192	6
San Francisco	4	0
San Mateo	55	5
Santa Cruz	11	0
Monterey	103	8
Ventura	6	2
Total	502	32

[1] One case in 1927 and 2 cases in 1931 from unknown sources and 5 cases attributed to "Marin and Sonoma area" in 1954 are not included.
[a] Counties without reported cases since 1927 are not included.

sampling frequency in a shellfish monitoring program. Monthly samples, for example, are not likely to coincide with an early period of bloom development. Biweekly samples are more useful, especially if a number of stations exist in the same region. Weekly samples, such as required by CDHS from commercial growers, are particularly helpful. Although most commercial mussel and oyster beds in California are within protected bays or estuaries, small increases in toxin levels from these areas often indicate more intense blooms in nearby ocean waters.

A third factor which may help to improve the chance of bloom detection in its early stages is described by Hurst and Gilfillan (1977). On the Maine coast, there is an early lag period when toxic blooms are "getting started" (i.e., when toxicity levels are low but detectable) and do not change greatly in intensity. This early stage may last up to two weeks before the bloom "takes off." It appears that once

TABLE 13.

Boundaries of selected toxic dinoflagellate blooms in California, 1962–89.

Year	Months Involved	Northern Boundary	Southern Boundary	Approximate Distance (Miles)[1]
1962	July–August	Jenner, Sonoma County	Piegon Point, San Mateo County	113
1969	September–December	Shelter Cove, Humboldt County	Salt Point, Sonoma County	108
1970	June–August	Mussel Point, Bodega Marine Lab, Sonoma County	Pescadero Beach, San Mateo County	98
1971	July–September	Bodega Head, Sonoma County	Natural Bridges State Park, Santa Cruz County	128
1980	July–August	Timber Cove, Sonoma County (Rock Scallop)	Rockaway Beach (Pacifica), San Mateo County	92
1981	September–October	Shelter Cove, Humboldt County	Rodeo Cove, Marin County	189
1984	February–March	Mussel Point, Bodega Marine Lab., Sonoma County	Natural Bridges State Park, Santa Cruz County	130
1985	March–April	Moonstone Beach, Cambria, San Luis Obispo County	Ventura Beach, Ventura County	184
1986	June–August	Mussel Point, Bodega Marine Lab., Sonoma County	Pescadero, San Mateo County	98
1989	August–November	Trinidad Harbor, Humboldt County	Pacific Grove, Monterey County	384

[1] Distances are straight-line measurements following major coastal contours.

toxin levels pass the 80–100 μg/100 level, rapid increases in shellfish toxicity follow.

Toxicity data from California do not reveal such lag periods. In fact, currently available data from the CDHS monitoring program indicate that toxin levels can increase rapidly, e.g., from barely detectable levels to those capable of causing serious illness in from seven to ten days. Illustrative of this, mussels in the Santa Barbara Channel went from 43 μg/100 g on March 25, 1985, to 450 μg/100 g on April 1, to 770 μg/100 g on April 4, and finally to 4,100 μg/100 g on April 10, 1985. This represented a roughly 10-fold increase in 7 days and a 100-fold increase in 16 days. Similarly, mussels from shoreline stations at Goleta increased from 65 μg on April 1 to 2,900 on April 9; and at Gaviota, from 49 μg on April 1 to 1,800 μg on April 9. Although increases in toxicity probably are not linear, the change at the Goleta site reflected an increase of approximately 350 μg/100 g per day for eight consecutive days. A profile of the 1985 Santa Barbara bloom is shown in Figure 9.

The 1989 bloom in Northern California also provided interesting data on rates of toxification in affected shellfish. The speed at which mussels can acquire the toxin was shown dramatically in Humboldt Bay during August when samples from the Eureka-Samoa Bridge increased from undetectable levels to 5,300 μg in only 7 days, an increase of 757 μg per day. The onset and course of the bloom within Humboldt Bay is shown graphically in Figure 10.

Because of the rate at which toxin concentrations can increase in shellfish, as a bloom intensifies, it is extremely important for health officials to be alert to potential problems, and to increase sampling frequency and geographic coverage, whenever the toxin reaches detectable levels. This alert state should occur even at locations many

TABLE 14.

Duration of nine selected toxic dinoflagellate blooms in California, 1962–89.[a]

Year	Date Started	Location	Date Ended	Location	Duration in Days
1962	July 20	Drakes Estero, Marin County and Pigeon Point, San Mateo County	August 24	Jenner, Sonoma County	36
1969	September 21	Shelter Cove, Marin County	December 5	Westport, Mendocino County	76
1970	June 8	Stinson Beach, Marin County	August 7	Stinson Beach, Marin County	61
1971	July 28	Drakes Estero, Marin County	September 7	Pescadero, San Mateo County	42
1980	July 20	Drakes Estero, Marin County	August 27	Tomales Bay, Marin County	39
1981	September 9	Dillon Beach, Marin County	October 23	Rodeo Cove, Marin County	45
1984	February 21	Drakes Estero, Marin County	March 29	Drakes Bay, Marin County	38
1985	March 6	Vandenberg Air Force Base, Santa Barbara County	April 30	Goleta, Santa Barbara County	56
1986	June 4	Drakes Estero, Marin County	August 21	Graywhale Cove, San Mateo County	79
1989	August 18	Pacific Grove, Monterey County and Santa Cruz–San Mateo County Line	November 10	Sea Ranch, Sonoma County	85

[a] Bloom durations are based on mussel and oyster samples with toxin levels of 100 micrograms per 100 grams of shellfish meat or greater.

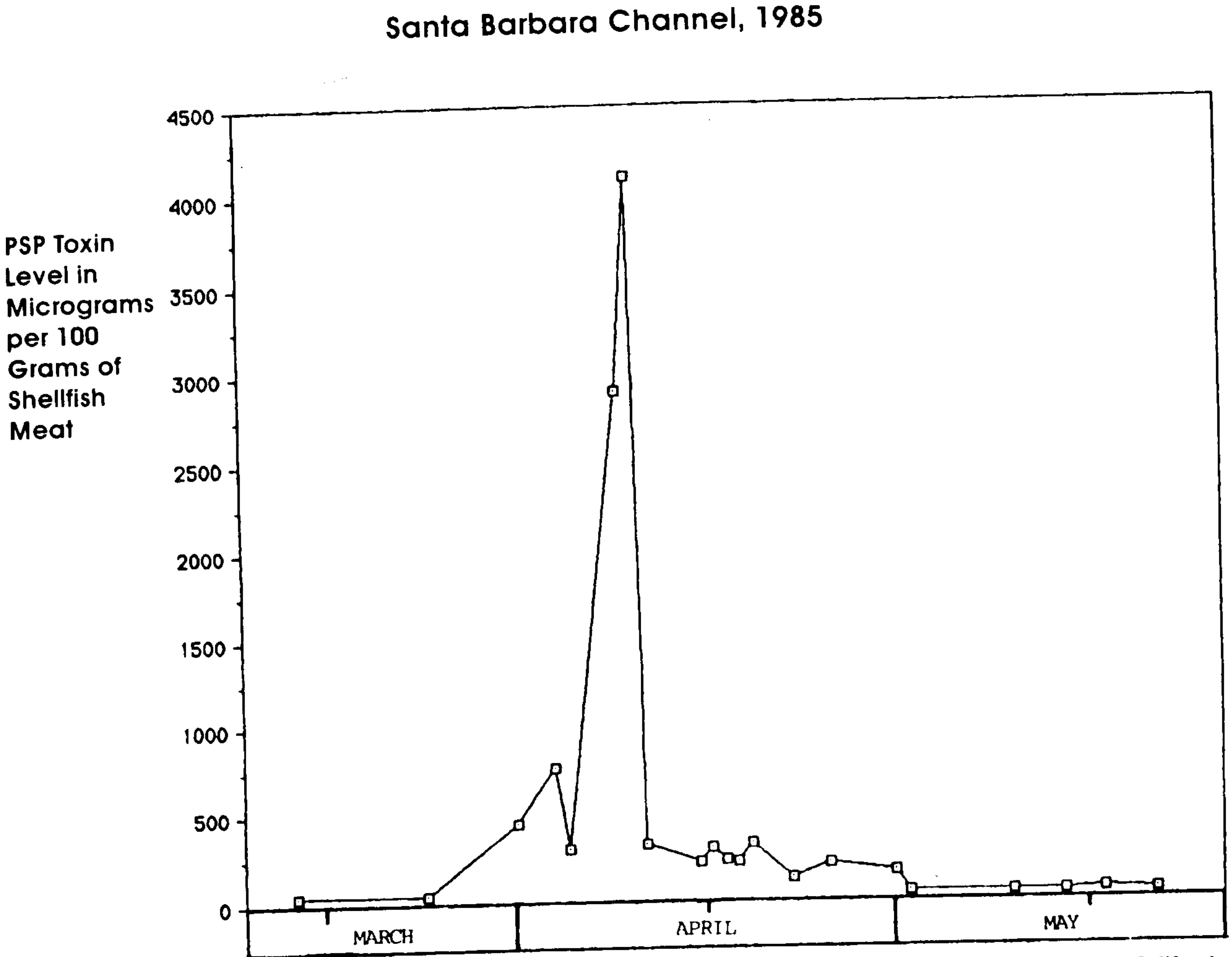

Figure 9. PSP toxin levels in mussel samples taken during the dinoflagellate bloom of 1985 in the Santa Barbara Channel, California

miles from the area of increased toxicity. For example, the CDHS and Santa Barbara County Health Department were alert to the possibility of a toxic bloom in the Santa Barbara Channel in April 1985 because of minor elevations in PSP in samples taken 2 and 3 weeks earlier at Vandenberg Air Force Base, about 70 miles away. Similarly, the rapid increase in toxicity at Humboldt Bay in September 1989 was not unexpected because of earlier PSP activity in Sonoma and Mendocino counties.

One should note that the PSP outbreak of 1980 in Marin and Sonoma counties occurred unexpectedly–the first indications being human illnesses–because of an absence of shellfish monitoring in Northern California during the preceding weeks.

Increased sampling during the August–November 1989 bloom enabled the CDHS to follow the rise and fall in shellfish toxicity in greater detail than ever before possible in California. Results of that sampling effort are shown graphically in Figures 11 and 12. In Figure 11, the sampling data are grouped and plotted according to six somewhat arbitrary geographic regions from Santa Cruz County in the south to Humboldt County in the north. This grouping allows one to visualize the northward movement of the bloom, the increase in bloom intensity as it moved northward, and the rates of increase and decline in shellfish toxicity along the selected parts of the coast. Figure 12 provides a composite of all sampling data obtained during the 1989 bloom, with the exception of duplicate counts obtained on the same date.

The northern shift in shellfish toxicity may reflect a general pattern of bloom development along this part of the coast, and, in fact, is mentioned by Sommer and Meyer (1937) with regard to the toxic blooms of 1927, 1929, and 1932 in the vicinity of San Francisco. Prediction of bloom movements would, of course, be very useful in a health protection program. More information is needed, however, before any general trends can be confirmed.

The speed at which shellfish can change from "safe" to "dangerous" is again revealed in the graphs in Figures 11 and 12. These graphs also show a fairly rapid drop in tox-

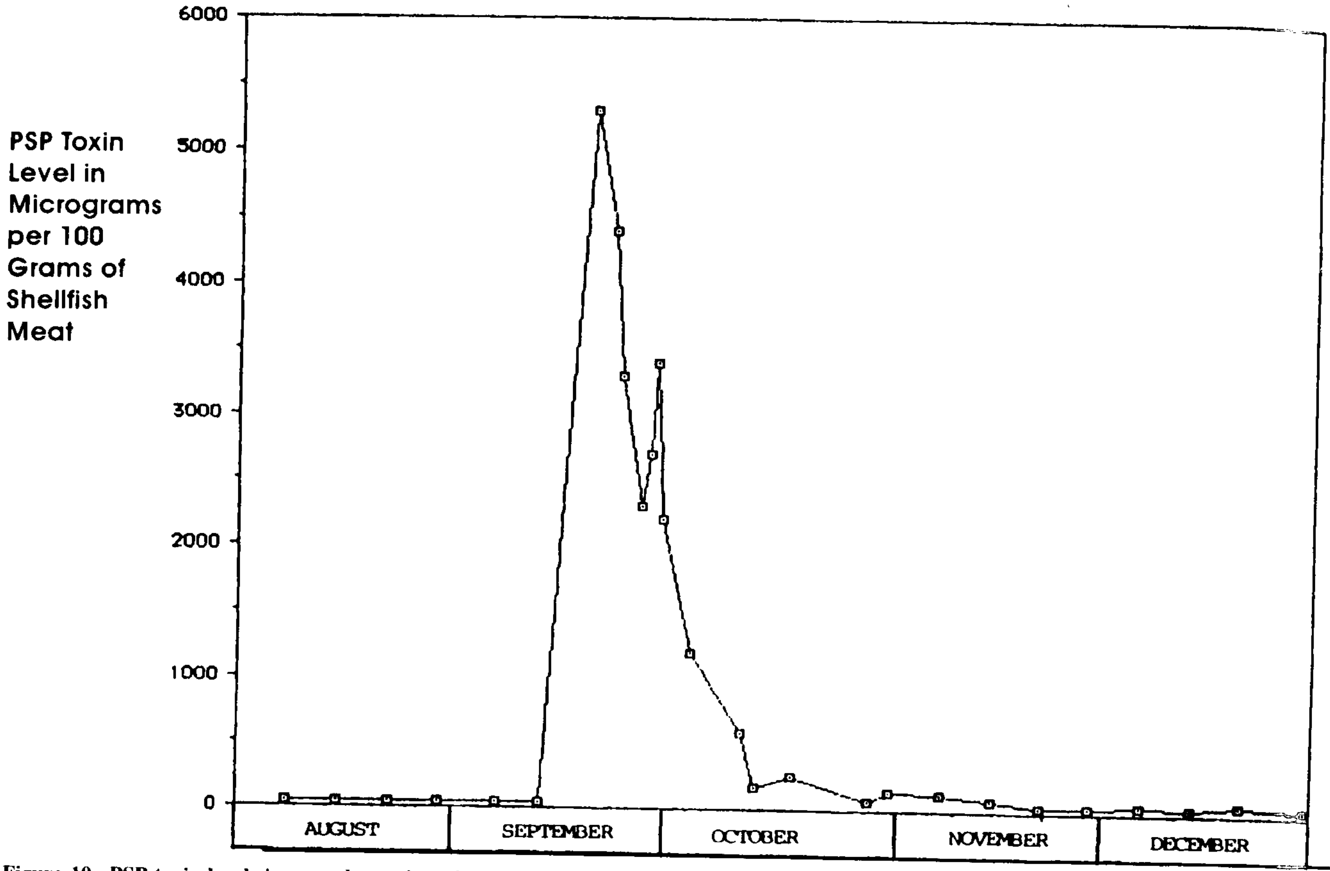

Figure 10. PSP toxin levels in mussel samples taken at the Eureka-Samoa Bridge and the Indian Island Channel, Humboldt Bay, California, during the period from August through December, 1989

icity after the peak is reached, although the drop is not as abrupt as the rise. The drop in toxicity is seen also in Figures 9 and 10 depicting the 1989 bloom in Humboldt Bay and the 1985 Santa Barbara bloom. For a public health protection program, it is important to recognize that once toxin levels begin to decline, the trend seems always to continue in a downward direction. This was true in 1989, as well as for all the major blooms in California since 1962. It would appear, therefore, that health officials need not be overly concerned that shellfish toxicity will rebound suddenly after special quarantines and public warnings are lifted.

Species Differences in Toxification and Detoxification

Differences in toxicity among different kinds of shellfish living in the same locality and exposed equally to toxic blooms reflect the ability to acquire, concentrate, and/or retain the toxin. In general, the rate of toxin uptake is higher than its rate of loss; that is, toxicity can increase from low to dangerous levels in a few days, while it may take two or three weeks for the shellfish to return to safe levels after the bloom subsides. Also, detoxification rates under natural conditions (i.e., in which the bloom itself is fading) are slower than when toxic shellfish are held in dinoflagellate-free water in depuration-type tanks.

The rate of toxin loss also varies among species of shellfish. In a study of detoxification in the blue mussel (*M. edulis*), the horse mussel (*Modiolus modiolus* Linnaeus), and the softshell clam (*Mya arenaria*), Hurst and Gilfillan (1977) calculated the time required for each species to drop from 1,000 μg/100 g to less than 80 μg/100 g to be 15 days for the blue mussel, 25 days for the softshell clam, and 35 days for the horse mussel.

Sommer and Meyer (1937) noted that California sea mussels [*Mytilus californianus* (Conrad)] held in water free of dinoflagellates lost about 50 percent of their toxicity in 10 days.

Notable examples of toxin retention are found in the Alaskan butter clam, [*Saxidomus giganteus* (Deshayes)] and the Washington clam [*Saxidomus nuttalli* (Conrad)] (Shantz and Magnusson 1964; Quayle 1969). Because of this characteristic, butter clams are considered permanently toxic in some areas of the Pacific Northwest and Alaska. In these areas, the toxin is retained primarily in the neck tissues, or siphon, leading some health agencies to advise that the siphon, especially the black tip, along with the viscera, be discarded before cooking.

Washington clams, including the siphon, are generally considered safe to eat in California. However, long-term retention of the toxin was demonstrated following the 1980

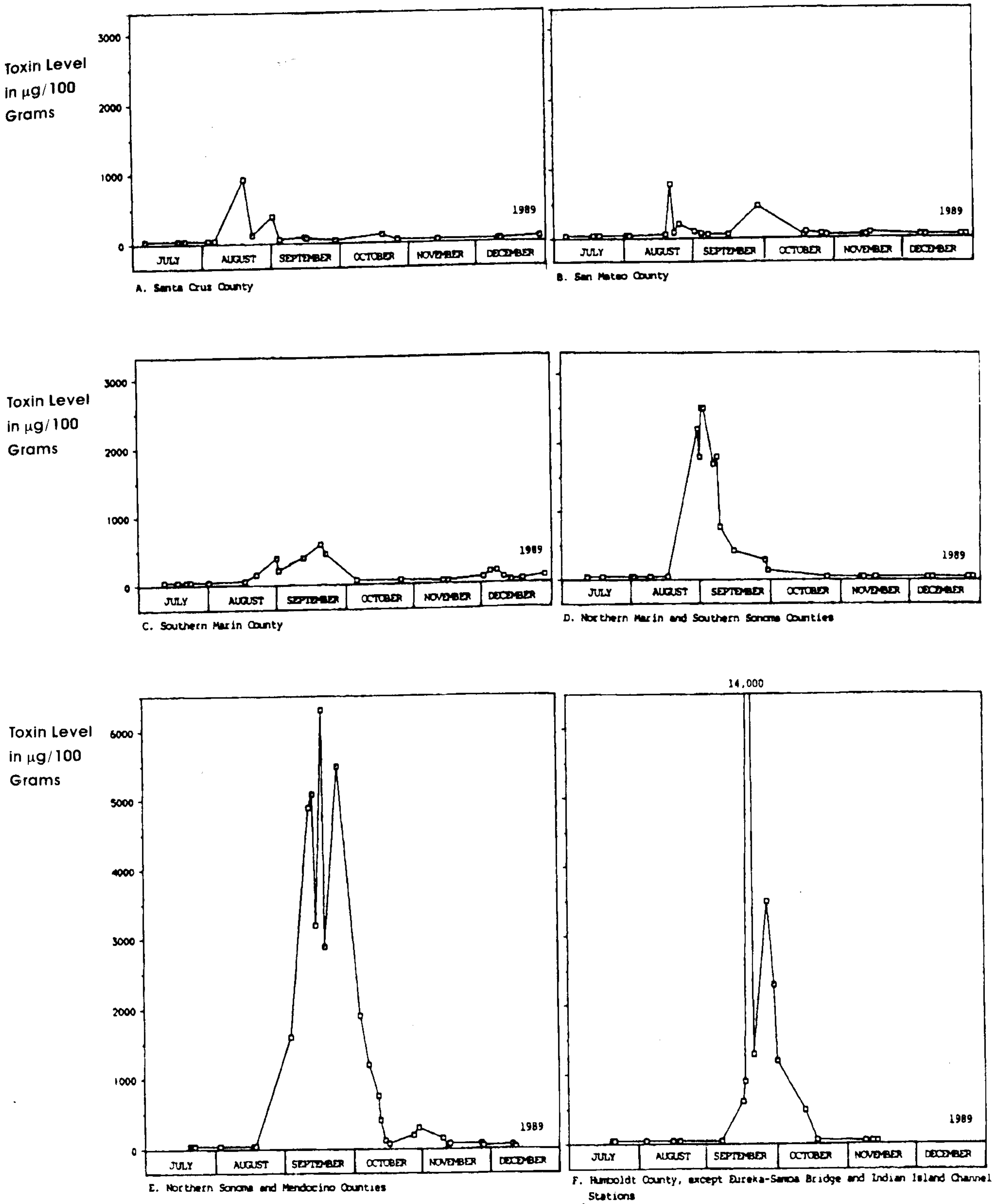

Figure 11. Paralytic shellfish poison levels in mussel samples from selected regions of the Northern California Coast during the toxic dinoflagellate bloom of August–November 1989

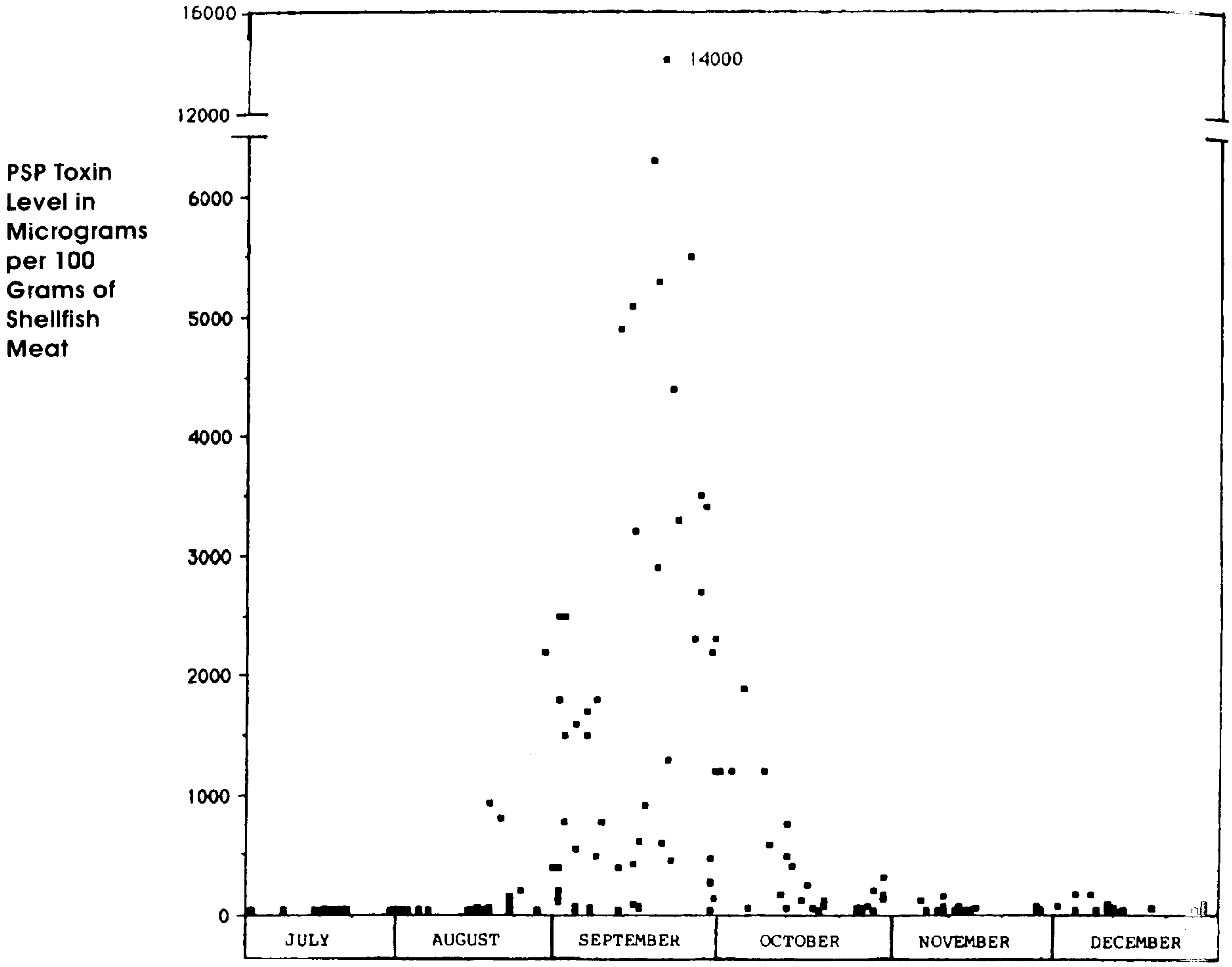

Figure 12. PSP toxin levels in mussel samples from the Northern California coast, Santa Cruz to Humboldt County, during the toxic dinoflagellate bloom of 1989

toxic bloom in Marin and Sonoma Counties. A special quarantine on the taking of Washington clams in these counties was imposed for two years, until December 1982.

In order to monitor toxin levels in Washington clams, numerous samples were taken from Bodega Harbor (Sonoma County) and Tomales Bay (Marin County) during the two-year period following the 1980 PSP outbreak. Some of these samples were divided so that the clam siphon was tested separately from the rest of the body. Results of these tests (Tables 15 and 16) confirm the persistence of the toxin and its concentration in the siphon tissues. Horseneck or gaper clams (*Schizothaerus nuttalli* (Conrad)) taken from the same sites in Bodega Harbor and Tomales Bay lost their toxicity soon after the 1980 bloom subsided (Table 17).

Data from the monitoring program also permit a comparison of toxin levels in the Pacific oyster [*Crassostrea gigas* (Thunberg)] and the bay mussel (*Mytilius edulis*) taken from the same beds in Drakes Estero, Marin County. A comparison was made of 31 samples taken from 1984 through 1988 in which either the mussels or oysters equaled or exceeded the 80 μg level. Of these, only one sample yielded toxin levels in oysters higher than in mussels (Table 18). In most other cases, the mussels greatly exceeded the oysters, with some mussels being five times more toxic than oysters. A similar difference between oysters and mussels was found during the 1989 toxic bloom, as shown in Table 19. These data confirm earlier observations on the propensity of mussels to acquire and concentrate the PSP toxin–an attribute which makes them the preferred indicator animal for toxic blooms and health hazard (Shumway and Hurst 1991). The wide differences in toxin levels between oysters and mussels from the same location suggest that the former may respond to concentrations of *P. catenella* by ceasing to feed or in some other manner which

TABLE 15.

PSP toxin levels in Washington clams from Bodega Harbor during and following the toxic dinoflagellate bloom of July–August 1980.[a]

Date	Body Less Siphon[1]	Siphon (Neck)	Whole Clam	Date	Body Less Siphon[1]	Siphon (Neck)	Whole Clam
7/30/80[b]	—	—	14,000	2/6/82	71	620	—
3/3/81	220	2,800	—	3/24/82	93	780	—
3/16/81	150	1,300	—	3/24/82	55	310	—
4/16/81	—	—	1,400	6/10/82	53	320	—
8/3/81	75	950	—	6/25/82	58	140	53
9/16/81	260	1,100	—	7/9/82	<44	150	—
9/28/81	220	1,500	—	7/23/82	55	210	—
10/26/81	130	1,300	410	8/21/82	90	164	—
11/23/81	79	530	230	11/14/82	—	—	<44
11/23/81	64	340	300	11/29/82	<44	58	—
12/21/81	68	490	160				

1 Body less siphon refers to all tissues of the clam, including the viscera and reproductive organs, except for the siphon.
a Toxin levels in μg/100 grams of shellfish meat.
b Campbell Cove.

prevents toxin uptake (Gilfillan and Hanson 1975, Gainey and Shumway 1988, Shumway et al. 1990).

PSP RISKS IN CALIFORNIA

In recent years, several investigators have commented on an apparent worldwide increase in shellfish toxicity problems (White 1982, WHO 1984, Maclean and White 1985, Anderson 1989, Shumway 1990); however, our data so far do not permit conclusions regarding overall increases in PSP activity along the California coast. The CDHS monitoring program has been too limited in duration and area covered to yet reveal long-term increases or cyclical patterns in toxic bloom phenomena. Increases in toxin levels noted since 1980 (Table 6) may be due simply to an increase in sampling during this period.

Similarly, it is difficult to detect any pattern in the reports of human PSP cases in California (Table 2). More cases occurred from 1927 through 1942, than for the longer period 1943 through 1989. This drop is almost assuredly due to the imposition of the six-month annual mussel harvesting quarantine in 1942, a better understanding of the causes of PSP, better public education activities, the coastal monitoring program, and (since 1981) the requirement that growers submit weekly samples for PSP testing. There is little doubt that the CDHS PSP Prevention Program has been effective in reducing the number of illnesses and deaths from PSP. However, the risk of poisoning remains and, for several reasons, may be increasing irrespective of any absolute change in toxic dinoflagellate bloom activities off the coast.

Two factors, in particular, increase the potential danger of PSP incidents in California. These factors are the expansion of commercial shellfishing activities and the increase in sport shellfish harvesting. Commercial shellfishing, until

TABLE 16.

PSP toxin levels in Washington clams from Tomales Bay during and following the toxic dinoflagellate bloom of July–August 1980.[a]

Date	Body Less Siphon[1]	Siphon (Neck)	Whole Clam	Date	Body Less Siphon[1]	Siphon (Neck)	Whole Clam
8/12/80	410	4,700	—	2/21/82	<44	440	—
8/28/80	95	4,500	—	3/5/82	75	1,400	280
3/17/81	230	410	—	3/6/82	51	420	110
4/9/81	—	—	170	4/24/82	54	600	—
5/4/81	—	—	270	4/27/82	<44	110	—
5/19/81	—	—	770	5/24/82	<44	140	—
6/21/81	—	—	890	6/13/82	—	—	<44
7/1/81	—	—	76	7/7/82	<44	<44	—
12/7/81	<44	850	140	7/20/82	—	—	69
2/3/82	—	—	380	8/17/82	—	—	57

1 Body less siphon refers to all tissues of the clam, including the viscera and reproductive organs, except for the siphon.
a Toxin levels in μg per 100 g shellfish meat.

TABLE 17.

PSP toxin levels in horseneck or gaper clams from Bodega Harbor and Tomales Bay during and following the toxic dinoflagellate bloom of July–August 1980.[a]

Date	Bodega Harbor	Tomales Bay	Date	Bodega Harbor	Tomales Bay
7/30/80	7,900[b]		4/10/81	<44	
8/12/80		560[c]	4/16/81	<44	
		<44[d]	5/7/81	<44	
8/28/80		<44	5/19/81		<44
11/19/80	<44[b]		6/21/81		<44
2/3/81	<44[b]		7/1/81		<44
3/3/81	52[c]		8/3/81	<44	
	<44[d]		9/28/81	62	
3/16/81	<44		10/26/81	<44	
3/17/81		<44	11/23/81	<44	

[a] Toxin levels in whole clams unless otherwise noted and in μg per 100 g of shellfish meat.
[b] Campbell Cove
[c] Body less Siphon
[d] Siphon

recently, was limited to the culture of oysters in enclosed bays and estuaries, especially Humboldt Bay, Tomales Bay, Drakes Estero, Elkhorn Slough, and Morro Bay. During the past decade, however, there has been a doubling in the number of shellfishing companies in California (i.e., from 10 in 1980 to 21 in 1988), along with changes in the types and locations of these operations.

One change, in particular, which has taken place during the past five years has been the development of a commercial mussel industry. Although commercial mussel harvesting is still much less than that of oysters, it is increasing every year. Several companies are involved exclusively with mussel culture, and many now include mussels, along with oysters, as principal products. Because mussels take up PSP toxins more rapidly than oysters and because they tend to concentrate the toxins at higher levels, greater care must be taken to ensure a commercial product free of PSP toxins.

Another change has been the expansion of the industry from protected locations within bays and estuaries to open coastal sites where direct exposure to toxic blooms is more likely to occur. To date, open-coastal commercial shellfishing operations have been limited to the Santa Barbara Channel, although CDHS has issued permits for research and development purposes in other offshore areas in Southern California. CDHS has not approved proposed commercial shellfishing activities along the open coast of Northern California because of the much higher PSP risks there.

Increased PSP risks associated with the culturing of shellfish, and especially mussels, in open-ocean locations are countered to some extent by the general coastal shellfish monitoring program, and, more importantly, by the mandatory PSP sampling requirements for commercial harvesters. However, because of the speed at which toxin levels can increase in shellfish during a PSP bloom, CDHS has concerns about risks occurring through possible loss or delay of samples in shipment to the testing laboratory. The

TABLE 18.

PSP toxin levels in Pacific oysters and bay mussels taken at the same location and at the same time in Drakes Estero, Marin County, 1984–1988.[a]

Date	Location in Drakes Estero	Toxin Level		Date	Location in Drakes Estero	Toxin Level	
		Oysters	Mussels			Oysters	Mussels
2/22/84	Baries Bar 1	230	77	6/25/86	Area 15	53	190
8/15/84	Area 19	<35	80	6/25/86	Area 38	160	660
8/22/84	Area 15	44	210	6/30/86	Area 38	41	320
8/27/84	Area 15	<35	170	7/2/86	Area 13	<37	110
				8/13/86	Area 15	<41	99
7/31/85	Area 15	<43	110				
8/5/85	Area 15	<43	130	5/20/87	Area 15	42	81
9/11/85	Area 15	<43	85	7/22/87	Area 15	<41	360
				7/27/87	Area 12	<40	240
4/9/86	Area 15	46	300	7/29/87	Area 12	<40	260
4/12/86	Area 15	43	150	8/5/87	Area 38	39	92
6/4/86	Area 15	<41	170				
6/11/86	Area 15	56	550	7/27/88	Area 15	48	100
6/15/86	Area 12	480	1,200	8/1/88	Area 15	73	230
6/18/86	Area 12	69	1,900	8/5/88	Area 12	57	330
6/19/86	Area 12	66	1,100	8/9/88	Area 12	42	82
6/23/86	Area 12	46	420	12/14/88	Area 17	40	87
6/25/86	Area 12	160	920				

[a] Samples listed include only those in which one member of the pair equaled or exceeded 80 μg/100 grams of shellfish meat.

TABLE 19.

PSP toxin levels in Pacific oysters and bay mussels taken from area 12, Drakes Estero, Marin County, at the same time during August and September 1989.[a]

	Toxin Level			Toxin Level	
Date	Oysters	Mussels	Date	Oysters	Mussels
8/24/89	110	860	9/10/89	47	470
8/28/89	70	330	9/12/89	41	270
8/29/89	220	59	9/13/89	44	220
8/30/89	58	500	9/19/89	69	260
9/5/89	59	270	9/21/89	52	210
9/7/89	49	450	9/24/89	41	150

[a] Samples listed include only those in which one member of the pair equaled or exceeded 80 μg/100 grams of shellfish meat.

loss of one week's sample or failure by the grower to submit a weekly sample could create a window within which a toxic bloom might not be detected. One way to minimize this risk is to group open-coastal shellfishing allotments in the same locality, as is currently being done in the Santa Barbara Channel, so that two or more operations serve to cover each other in early detection of PSP blooms. Another solution, which, unfortunately, is not currently available, is a simpler test for PSP–that is, one which could be used by local laboratories or, possibly, by the shellfish companies themselves. If such a test were available, then it might be possible to test all shellfish harvests prior to marketing during periods of potential risk. Efforts to develop such a test need to be encouraged.

The annual mussel sport harvesting quarantine is designed to discourage the public from taking mussels during that part of the year having the highest PSP risk. However, it may not be totally effective in achieving this goal. Although an effort is made to inform the public through press advisories, posting of quarantine signs, and other public announcements, some people are not reached. These persons may not know about PSP and assume that mussels are safe at all times. Others, especially recently arrived immigrants, may not be able to read the warning signs and other public notices, even though they are printed in several languages, or they otherwise may not be able to fully appreciate the risks.

Whereas some people may not be able to fully understand the quarantine notices, others, including many long-time residents, are known to simply ignore the warnings. This is especially so because of the very sporadic nature of PSP outbreaks, both in time and location, which inevitably leads to some complacency. This is particularly true if a number of years pass without any reported PSP incidents.

Another problem inherent with an annual, preventive quarantine is that warnings are being issued even when the mussels may be safe to eat. Indeed, it is well known that some people frequently ignore the warnings and consume mussels without ill effects. This reinforces complacency by making the quarantine seem unnecessary.

The most important characteristic of toxic dinoflagellate blooms in California from the aspect of health risk assessment is the speed at which they develop and at which affected shellfish can change from safe to dangerous food items. The wide range of human susceptibility to the PSP toxin further complicates the problem because it is difficult to assess the public health risks associated with particular toxin levels. Add to these factors the unpredictable nature of bloom events, both in time and location, and the magnitude of the CDHS PSP Prevention Program can be appreciated.

Because of the above factors, the single most important element in the State's effort to protect the shellfish consumer is the coastal PSP monitoring program. It provides information to establish emergency quarantines, issue special public warnings during the normal quarantine period, expand the mussel quarantine to include clams and other bivalve mollusks, and, when necessary, close commercial shellfishing operations. Without this monitoring program, the first indications of a toxic dinoflagellate bloom would be actual cases of PSP–an unacceptable alternative.

Effectiveness of the monitoring program depends on sampling frequency and the number and distribution of sampling stations. And while CDHS has concerns that the low sampling frequencies in certain coastal counties and the relatively long distances between some adjacent sampling stations might allow a toxic bloom to develop without early detection, recent efforts by CDHS to gain resources to increase sampling activity have improved this situation. However, these efforts need to be sustained and further improved if early detection of coastal PSP activity is to be ensured.

CONCLUSION

PSP is a continuing and possibly increasing public health concern in California. Records of PSP illnesses since the major outbreak of 1927, along with sampling data obtained through the CDHS shellfish monitoring program since 1962, indicate that toxic dinoflagellate blooms are not an uncommon occurrence along the California coast. Because of the unpredictable appearance of toxic blooms and the speed at which dangerous levels of the PSP toxins can accumulate in exposed shellfish populations, public health protection requires a vigorous, year-round prevention effort.

The California shellfish monitoring program and testing of shellfish from commercial harvesting areas since the 1980 PSP outbreak have identified a number of PSP toxic blooms resulting in dangerously high toxin levels in coastal bivalve mollusks. Three of these recent blooms occurred during the historically "safe" nonquarantine period and posed especially high risks to sport shellfish harvesters.

Detection of these early blooms, as well as several which occurred during the quarantine period, enabled CDHS and local health agencies to issue special quarantines, close commercial harvesting areas, alert the sport shellfishing public, and take other public health protection measures. As a consequence of these actions, it is believed that numerous PSP illnesses were prevented.

The monitoring program also provides information which expands our understanding of the geography, dimensions, duration, and dynamics of toxic blooms and the toxification of affected shellfish. This information provides a foundation upon which improvements in sampling strategies and more efficient deployment of field and laboratory resources during the course of toxic blooms can be based.

Experience in monitoring for PSP over the past several decades underscores the fact that this is a problem which cannot be neglected by public health agencies. In California, a sustained effort, particularly in the early detection of toxic dinoflagellate blooms, is required to ensure protection of shellfish consumers. In addition, that effort ensures the safety of the State's expanding maricultural industry. Indeed, experience in other seafood industries has made clear the economically devastating effects that toxic problems can cause to such industries, and especially when they are nascent industries such as commercial shellfishing is in California at this time.

In sum, we believe the California PSP Prevention Program has been effective and has provided expanded insights into this unusual malady. We think the experience gained from the California program, especially in recent years, should be useful to other states and countries confronting similar circumstances.

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