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ECONOMIC IMPACT OF PARALYTIC SHELLFISH POISON ON THE OYSTER INDUSTRY IN THE PACIFIC UNITED STATES

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ABSTRACT

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The oyster industry on the west coast of the continental United States extends from Morro Bay, California, north to and including Puget Sound, Washington. Periodic outbreaks of paralytic shellfish poison caused by dinoflagellates of the genus *Gonyaulax* have resulted in reported symptoms and even death from consumption of contaminated shellfish. Although no deaths and only two reported outbreaks have affected commercial oysters, the fear of paralytic shellfish poison results in seasonal depressions in oyster markets, even when outbreaks are not present. This, coupled with inaccurate or misleading information distributed to the public, not only affects marketing of oysters under normal circumstances, but also has an impact on the interstate shipment of nonaffected, Health Service-approved oysters from nonaffected areas. Because of the nature of the west coast industry, both in terms of investment for acquisition of seed and cost of structures used in grow-out techniques, interruptions in the marketing of oysters have a drastic impact on the oyster industry. This study reviews the economic impact of paralytic shellfish poisoning, the factors that increase the impact beyond the normal response, and requirements necessary to lessen the impact on the oyster industry.

INTRODUCTION

Both the oyster industry and paralytic shellfish poisoning (PSP) have long histories in western North America. Ironically, the two have not been directly associated until recent years. Paralytic shellfish poisoning has been primarily associated with the noncommercial harvest of mussels and clams and has been reported from the Pacific northwest for 184 years (Fortuine, 1975). The west coast oyster industry is approximately 130 years old and has had two reported incidents of PSP; the first in 1962, and the second in 1980 (Sharp, 1981).

The west coast industry

The oyster industry of the U.S. Pacific states is located in Washington, Oregon, and California. Historically, the stimulus for its development was the California gold rush of 1849, which attracted a large population from the east coast. During this period the oyster fishery was the largest fishery in the United States, and oysters were a major component in the diet of east coast

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populations (Dressel and FitzGibbons, 1978). As people moved west, they brought with them a preference for oyster products.

The natural beds of native oysters (*Ostrea lurida*) on the west coast were quickly depleted or overtaxed in all three west coast states in attempts to meet San Francisco's market demand. Both Washington and California established large grow-out industries, first based on temporary holdings of adult eastern oysters (*Crassostrea virginica*) and later large seed oysters, both shipped by transcontinental rail. These shipments were necessary because of the eastern oysters' inability to successfully reproduce in colder west coast waters. Despite this handicap, both California and Washington developed massive industries. Record harvests of over 1 million kg of meat are reported for California in 1899 and 4000 bushels (1 bushel equals approximately 1 basket or 14.5 kg) of oysters for Washington in 1918. With the decline in water quality and other related factors, the industry based on the culture of the eastern oyster collapsed in Washington in 1919 and in California in the 1930s (Beattie *et al.*, 1981; Conte and Dupuy, 1981).

Experiments with seed of the Pacific oyster (*C. gigas*) shipped from Japan to Washington and California during the early 1920s demonstrated that it was biologically and economically feasible to establish an oyster industry based on this species. With seed sources from Japan, and later from certain bays in Washington and Canada that have water temperatures and conditions that promote successful reproduction of the Pacific oyster, the west coast industry is again a major producer of oyster products. The development of hatchery systems to produce needed domestic seed has added to the industry's potential growth. Current approximate production rate in shucked pounds of oyster meat is 2.7 million kg for Washington, 0.5 million kg for California, and 0.1 million kg for Oregon (Chew, 1978; Beattie *et al.*, 1981; Conte and Dupuy, 1981; Qualman, 1981; Glude and Chew, 1982; K. Chew, personal communication, 1982) (Fig. 1).

Paralytic shellfish poisoning

Paralytic shellfish poisoning is a form of food poisoning that can affect mammals, including humans. The toxic substances are produced by certain species of dinoflagellates which can be accumulated in shellfish and passed on to vertebrates that consume the shellfish. The neurotoxic substance produced was originally termed saxitoxin, after the Alaskan butter clam (*Saxidomus giganteus*) from which the toxin was originally isolated. Other isolates associated with PSP include gonyautoxin I through IV and neosaxitoxin, precursors, and more isolates will probably be discovered in the future. The pharmacological action of all these isolates appears to be similar to that exhibited by saxitoxin; the blocking of sodium-ion influx through activated membranes. The poisoning effect ranges from mild tingling sensations to muscular paralysis, and even death through respiratory failure. The toxins are heat stable at lower pH and cannot be destroyed by heating, or by those activities applicable to ordinary food processing (Shimizu, 1982).

The dinoflagellates associated with PSP on the west coast of North America are *Gonyaulax catenella*, reported in incidents from Alaska to Mexico, and

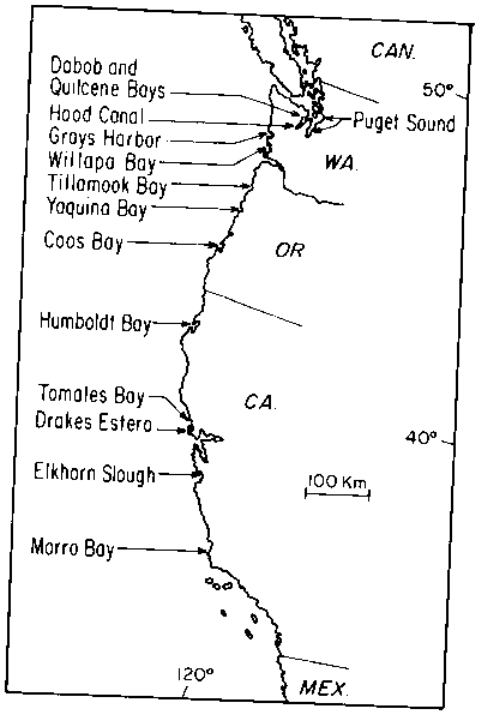

Fig. 1. United States west coast oyster production areas.

Gymnodinium breve, reported from the Pacific coast of Mexico. First reports of PSP were made by Captain George Vancouver during exploration of the northern British Columbia coast in the spring of 1793, and an incident near Sitka, Alaska, in 1799 (Vancouver, 1798; Khlebnikov, 1835). Both episodes of poisoning were attributed to consumption of mussels and are considered PSP, as the clinical and epidemiological features were quite typical (Fortuine, 1975). Numerous incidents of PSP due to mussel and clam consumption have been reported over the years; however, few incidents have involved oysters, and no deaths from PSP have been attributed to commercial oysters. California has had more reported cases of PSP than any other state (Table I) and is the only west coast state to report PSP due to consumption of commercial oysters. Both incidents resulted from toxic dinoflagellate blooms in oyster beds on the central California coast, the first occurring in 1962 and the second in 1980 (Table II).

The result of PSP laboratory analyses are reported as micrograms (μg) of toxin per 100 g of shellfish meat. For brevity, this is reported as μg of toxin. Approximately one millionth of a gram is sufficient to kill a mouse, the test animal, on injection. Humans exhibit different levels of resistance to the toxin, however, it is suspected that human death can occur from ingestion of a few milligrams of the toxin (Sharp, 1981).

State public health agencies conduct PSP monitoring programs based upon available budget, budget priority, and past history of PSP outbreaks. All state

TABLE I

Cases of paralytic shellfish poison reported in the United States and Canada from 1793 to 1977[a]

Locations	Years	Number of cases	Deaths
California	1903, 1915, 1917, 1918, 1927, 1929, 1932, 1936, 1939, 1943, 1944, 1946, 1948, 1954, 1969, 1980	>509	32
Oregon	-----, 1933, 1957[b]	>22	1
Washington	1942, 1972, 1978	26	2
Maine	1943, 1972	>25	--
Alaska	1799, 1934, 1944, 1954, 1962, 1973, 1976, 1980, 1982	160	103
British Columbia	1793, 1942, 1957, 1972	12	1
Nova Scotia and New Brunswick	1936, 1945, 1957, 1958, 1976	82	2
Quebec	1948, 1954	9	4
Massachusetts	1972, 1974, 1980	51	--
Rhode Island	1972	1	--
New Hampshire	1972	6	--
Florida	1973, 1974	6	--
Tennessee	1980	5	--
		>914	145

[a]Modified from Verber (1982).
[b]Unconfirmed, but reported by a Brookings, Oregon, physician.

agencies use the toxin level of 80 μg as the quarantine level. However, because of budget limitations and history of outbreaks, the states use various options in establishing shellfish harvesting regulations. Those states with regular quarantine periods either impose an annual quarantine on sports-harvested shellfish without monitoring or impose a year-round quarantine based on past experiences with PSP.

California, with its many past outbreaks of PSP, has imposed an annual quarantine on sports-harvested shellfish since 1939. The annual quarantine period lasts from May through October 31 on all coastal areas including bays, inlets, and harbors. Oregon, with the fewest reported PSP incidents, has no annual quarantine period, but monitors shellfish from about six locations every 2 weeks beginning in mid-April and extending to the end of September. Washington began testing for PSP in the 1930s and since 1942 has annually quarantined the sports-harvesting of geoducks, horse clams, hardshell clams, and mussels on all beaches from Dungeness Spit to the Columbia River from April 1 through October 31. Alaska, which has experienced the most PSP-related deaths, has initiated a year-round shellfish sports-harvest quarantine on

TABLE II

California paralytic shellfish poisoning, cases and deaths: July 1927 to July 1980[a]

Year	Cases	Deaths	Month of onset	Type of shellfish
1927	103	6	July	Mussels
1929	16	0	July	Mussels
	25	0	July	Mussels
	13	1	Aug.	Mussels
	6	3	Aug.	Clams
1930	2	0	July	Mussels
1931	2	0	March	Mussels
1932	1[b]	1	April	Abalones[b]
	14	1	July	Mussels
	2	0	July	Clams
	2	0	July	Mussels
	8	0	June	Mussels
	1	0	July	Mussels
	1	0	June	Mussels
	15	0	July	Mussels
1933	5	0	Sept.	Mussels
	7	0	July	Mussels
1936	3	2	May	Mussels
1937	4	0	Aug.	Mussels
	10	0	Sept.	Mussels
	3	0	Aug.	Mussels
	2	0	Unk.	Mussels
	8	0	Oct.	Mussels
1938	3	0	May	Mussels
1939	58	5	June	Mussels
	6	1	July	Mussels
	9	2	June	Clams
	3	0	June	Clams
1943	4	0	Aug.	Mussels
	16	4	Aug.	Mussels
1944	9	2	Oct.	Mussels
	3	0	Oct.	Mussels
1946	3	1	July	Mussels
1947	1	0	May	Clams
1948	3	1	June	Mussels
1954	5	0	Aug.	Mussels
1962	4	0	Aug.	Oysters
1969	12	0	Sept.	Mussels
	3	0	Sept.	Mussels
1971	7	0	Aug.	Mussels
	4	0	Aug.	Mussels
	4	0	Sept.	Mussels

1980	61	0	July	Oysters
	36	1	July	Mussels
	2	1	July	Scallops
Total	509	32		

[a]Modified from Sharp (1981).
[b]The species of shellfish involved in this incident is uncertain, but it was probably not abalone.

all coastal waters (Miescier, 1982). During those periods when no quarantine is in effect, if toxin levels are found near 50 μg, then the monitoring efforts are increased; and if levels of 80 μg are detected, quarantine is enforced. Commercial shellfish are not affected by annual quarantines, however, they are subjected to quarantine if a level of 80 μg toxin is detected in the grow-out area. Since the California outbreak in 1980, all Pacific states have reevaluated their monitoring programs in relation to the commercial shellfish industry and have considered expanding the programs in cooperation with the industry.

The impact of PSP on the west coast oyster industry is varied, both in intensity and time frame. The impact ranges from subtle influences during the annual sports-harvest quarantine periods to the more drastic impact, that of the ability of the industry to reseed for future markets. The complexity of response results from the public's lack of understanding of both PSP and the commercial oyster industry, and the nature of the industry itself.

PSP factors that affect the oyster market

There is need for increased public education concerning PSP and its relationship to the commercial oyster industry. The greater public sector does not understand that the annual quarantines apply to sports-harvested mussels and clams and not to commercial products. Commercially produced oysters are not subject to quarantine except during periods when elevated toxin levels are detected in or near commercial beds. Commercial oyster growers in cooperation with state departments of health services now monitor these areas for the presence of elevated toxin levels, and these departments, along with the Federal Food and Drug Administration, subject the products to regulations established for the protection of the public.

Lack of understanding of PSP by the public is further complicated by misleading information distributed through the news media and inadequate information released by involved agencies. Misleading information distributed through the news media during normal quarantine periods, when the toxin levels are even nonexistent, is extremely harmful to the oyster industry. The annual quarantine period was established to protect the public from nonmonitored populations of clams, mussels, or oysters taken through sports harvesting. The failure of the news media to adequately differentiate between these populations and certified commercial oysters causes depressions of sales that last throughout and beyond the annual quarantine period. When a PSP outbreak does occur in a commercial oyster area, the news media again more often fails to make a distinction between oysters that are quarantined and recalled and those oysters harvested from other areas that are not affected. As

a result, safe oysters that were harvested and packaged hundreds of kilometers away, and even imported from other states fail to move in the market.

The primary channel for PSP information released to the news media is from the state and county health service agencies. Although cooperative progress has been made, primarily between the various state offices of health service and the oyster industry, problems have existed at the county level. Industry representatives have stated that there is little cooperation on the county health services' part in making an effort to differentiate facts when releasing information to the news media. Some county staffs in turn have stated that their primary concern is public safety, and their responsibility is limited concerning the instruction of the news media as to what is not a safety hazard (Paralytic Shellfish Poison Management Workshop, 1982). Attempts are being made to establish better communication and understanding among the groups; both to protect the public sector from harmful results of PSP and to prevent the negative impact of inadequate information released to the news media.

Industry factors that increase economic impact

The impact of PSP on the Pacific states' oyster industry is more extensive than that experienced by the industry in the Atlantic states. This is based on the difference in species and culture techniques. Lutz and Incze (1979) reported that PSP has marginal effects on the west-coast shellfish industry, but their study was prior to the 1980 California outbreak and the extensive analysis made on its impact. The eastern oyster is native to the Atlantic states, and the source of seed is through natural spawning and set. The eastern oyster industry is essentially bottom culture, whereas many oyster growing areas on the west coast require off-bottom culture which involves additional capital investment. The west coast industry, based on the culture of the nonnative Pacific oyster, obtains its seed from select bays in the Pacific northwest, from the emerging hatchery industry, and from Japan. In order to successfully reproduce, Pacific oysters require about 3 weeks of water temperatures between 19 and 20°C, salinities of approximately 20-25 parts per thousand, and ideal water current patterns that allow proper set. Successful natural reproduction and set do occur frequently in portions of Pendrell Sound, British Columbia, and in Dabot, Quilcene, and Willapa Bays in Washington State.

The Washington oyster industry has moved away from Japanese imported seed and now relies on its own natural set and hatchery-produced seed. The industry will continue to take advantage of the natural set, however, the rising cost of shipping cultch between setting areas and the unreliability of obtaining a set of commercial density is encouraging the expansion of hatchery-produced seed and remote setting of eyed larvae. In 1981 the industry obtained 40% of its seed through natural set, an occurrence in 7 out of every 10 years (Beattie *et al.*, 1981; K. Chew, personal communication, 1982), and 60% through setting eyed larvae.

Oregon and California water termperatures are considered too cold to promote successful reproduction of the Pacific oyster. Some spat fall occurred in both Humboldt and Tomales Bays in the early 1960s (Span, 1978), however, it has been erratic and not considered a dependable occurrence. The Oregon

industry has had problems maintaining a consistent source of seed. Commercial seed has been purchased from hatcheries in the state and from Japan and Washington; however, North American seed, which is preferred by many Oregon growers, is not always available (Qualman, 1981). The California industry also obtains seed from Washington producers, but most of the producers still rely on Japanese seed, eyed larvae from Oregon and Washington, and seed from California hatcheries. These hatcheries produce spat on mother shell, cultch-free seed, and eyed larvae for remote setting. Although hatchery systems are viewed by the industry as the most desirable direction in which to proceed, these systems have not matured to the extent of supplying the industry's total needs. The California industry still maintains links with the Japanese seed industry and will do so until a stable domestic supply is established.

Japanese seed cost has risen dramatically since the late 1970s. The increase is due to rising labor costs in Japan, the unfavorable U.S. dollar/Japanese yen exchange, and lower seed production (K. Chew, personal communication, 1982). Japanese seed costs approximately $60-65 per case, each case containing approximately 600 mother shells with ±20 attached spat. Washington seed costs average about $53 per case, but when shipped to central northern California, there is an additional transportation cost of about $1,000 a truckload. For off-bottom culture the mother shell is usually shipped punched and strung at 100 shells per wire, with each shell averaging 20 spat. Each stringer has a value of approximately $4.50. The origin of the seed is either hatchery or natural set.

In order to reduce the cost of shipping shell, some west coast hatcheries are shipping eyed larvae for remote setting in temperature-controlled tanks at the production site. Hatchery price for eyed larvae is approximately $100 per million larvae, and once set averages about 20 spat per shell. Cost to the operator including materials, energy, and labor is about $35 per case. No matter what the source of seed, if it does not occur naturally at the grow-out site, it represents a considerable investment with no returns for 2½ to 3 years when the oysters reach market size.

The grow-out techniques used by the west coast industry include primarily bottom culture and off-bottom culture such as rack, stake, raft, rope, and bag culture. The majority of the oysters are produced by bottom culture in Washington and northern California. The off-bottom forms of culture are practiced as a more efficient means of production in a given area, to avoid destructive predators, because of environmental law, or a combination of these factors. Although a very efficient means of culture, off-bottom culture requires additional capital investment in the materials or structures used. Most off-bottom culture occurs in Drakes Estero, California, in the form of rack and stake culture. This area was also in the center of the 1980 PSP outbreak. A single rack, or bent, is constructed from pressure-treated wood that sold for $441.25 per 1000 board feet in 1979. A single bent costs approximately $92 in wood material and hold 60 strings of oysters. Each string consists of a 2.59-m wire threaded through 12 punched mother shells with attached oyster spat, with each mother shell separated by a short, tube spacer. Individual strings of

oysters, termed a unit, are shaped into an inverted "u" and positioned to straddle a horizontal beam on the bent where they remain suspended in the water column. A single stringer costs approximately $1.92 in materials including wire, spacers, and seed oysters. There are currently over 2,100 bents producing oysters in Drakes Estero (C. Johnson and T. Johnson, personal communication, 1982).

Stake culture in Drakes Estero consists of an 81.3-cm length of wire, or wire stake, threaded through three mother shells containing spat with each shell separated by a tubular spacer. At the spike end of the stake the wire is punched through a plastic disk to aid in anchoring the stake and to prevent it from sinking into the substrate as the oyster spat grow and increase in weight. Four stakes are considered a single unit and material cost for a single unit is $1.92. There are currently 160,000 units being cultured in the Estero (C. Johnson and T. Johnson, personal communication, 1982).

1980 CALIFORNIA PSP OUTBREAK: A CASE STUDY

The 1980 California PSP outbreak offers the best-documented impact of PSP on the commercial oyster industry. The information available from this incident has application to the understanding of the effect of PSP on other oyster-growing areas internationally.

The 1962 PSP outbreak (Table II), which was the only other incident of reported PSP-oyster-induced illness on the west coast, was a small outbreak that involved four individuals. In contrast, the 1980 PSP outbreak was the second largest PSP incident in the state's history and was centered in a major oyster producing area: Drakes Estero and Tomales Bay.

In the 1980 outbreak, 61 cases with no deaths were attributed to commercial oysters; 36 cases with one death were attributed to sports-harvested mussels; and one death was attributed to the consumption of the viscera of a single, sports-harvested scallop. These were the first reported deaths attributed to PSP in California since 1948. The toxic poisoning associated with the consumption of mussels was more severe than the cases due to oysters. There were no respiratory failures due to oyster consumption, but six reported respiratory failures were due to consumption of sports-harvested mussels. Of the 61 oyster-related cases, 41 individuals experienced minor symptoms and did not seek medical assistance, 10 were examined by physicians and released, and 2 were hospitalized for observation (Sharp, 1981).

The first indications of the 1980 PSP outbreak originated during the weekend of July 19-20. Communications between oyster operations in Drakes Estero, personnel of the Department of Fish and Game, and personnel of the Department of Health Services concerning reported poisonings were confirmed by the night of July 20, and emergency measures were enacted on July 21. Commercial operations in Drakes Estero voluntarily closed sales on July 20, 1980.

Although the outbreak occurred during the annual California sports-harvest quarantine period, it was apparent that segments of the population were unaware of the quarantine, or were disregarding warnings. Health Services

intensified its efforts to warn the public sector and began a recall of affected and potentially affected oysters. A PSP sampling and monitoring program was established for much of the northern California coast and included the major oyster-producing areas of Drakes Estero and Tomales Bay. Shellfish from both of these bays, including oysters, were found to be above the 80 μg limit. The highest recordings for commercial oysters were 5,500 μg from Drakes Estero and 2,100 μg from the upper end of Tomales Bay. Other high readings were 16,000 μg from bay mussels (*Mytilus edulis*) in Tomales Bay; 14,000 μg from sea mussels (*M. californianus*) from Stinson Beach, north of San Francisco; and 14,000 μg from Washington clams (*Saxidomus nuttalli*) from Bodega Bay, north of Tomales Bay (Sharp, 1981).

The Department of Health Services established a quarantine on the harvest and sale of commercial oysters for the period in which samples exhibited toxin levels above 80 μg. Drakes Estero, which consists of four finger bays, exhibited levels above 80 μg as follows: Creamery Bay, 10 days; Home Bay, 18 days; Schooner Bay, 23 days; and Barries Bay, 18 days. Oysters sampled from Tomales Bay demonstrated toxin levels below 80 μg in the lower bay and above 80 μg near the upper end and the mouth of the bay. Exceptions were noted in areas where fresh water inflow may have retarded the toxic bloom or where bottom culture activities resulted in lessened exposures to the blooms during periods of low tide (Sharp, 1981). Oyster samples from these different areas exhibited toxic levels above 80 μg in a range from 4 to 22 days.

Although the 1980 PSP outbreak was confined to an area from just south of San Francisco Bay to a point approximately 77.3 km north of Tomales Bay, its impact affected oyster growers in California, Oregon, and Washington. News releases on July 25 strongly urged that all persons avoid shellfish gathered from the entire California coast. It was not until August 8 that the Department identified the range of the outbreak (Sharp, 1981). The immediate impact was 100% closure of oyster production areas in the affected zone for a maximum of 30 days. This included voluntary closures in Drakes Bay beginning on July 21 and extending to August 20. The quarantine was lifted on August 20, however, 2 weeks were required to harvest oysters and reopen markets.

The San Francisco area is a critical market to all west coast oyster producers. Because it was located in the center of the 1980 PSP outbreak range, and news media coverage was so intense, the marketing of oysters in this area virtually ceased to exist. Although public response and market loss during a PSP outbreak is expected, the problem was intensified by the distribution of misleading information and failure to distinguish between affected shellfish and oysters harvested from nonaffected areas. Oysters harvested from Elkhorn Slough, Morro Bay, and Humboldt Bay in California, and from Oregon and Washington could not be marketed in most of California. This resulted in a near 100% closure of markets for California producers and an approximate 25% market loss to producers in Oregon and Washington that market their products in California. The problem was further complicated by a lack of positive media exposure after the quarantine was lifted. This resulted in depressed markets through Thanksgiving and Christmas, a usual period of greatest oyster sales. Additional loss experienced by the California growers was approximately

$25,000 in harvested and processed oysters that were condemned and destroyed as the result of quarantine and market recall. Because the quarantine mandated that harvesting of oysters cease in the affected area, no oysters were harvested in Tomales Bay and Drakes Estero during late summer. A common occurrence in many Pacific coast growing areas is a recognized phenomenon of undetermined cause termed "summer mortality." Mortalities above 50% can be experienced among 2- and 2½-year-old Pacific oysters if they are left in the grow-out area in late summer. Oyster loss in Drakes Estero due to summer mortality and documented by the California Department of Fish and Game was 56%, valued at $33,796 (Dahlstrom, 1980). The total economic loss reported by growers in California, Washington, and Oregon from the 1980 PSP outbreak was approximately $630,456 (R.F. Studdert, personal communication, 1982).

The most severe impact of the 1980 PSP outbreak was the disruption of the market that affected the cash flow necessary for reseeding by commercial growers. As discussed earlier, the industry depends on purchase of seed from limited natural sets in the United States, limited hatchery production, and Japanese sources; a substantial investment with no economic returns for 2-2½ years. The 1980 outbreak was a natural disaster that affected the productivity of the industry in ways comparable to natural diasters in the traditional commercial fishery. It was a resource disaster caused by a natural phenomenon that resulted in serious disruptions of the industry and has affected future production. In addition to affecting reseeding, the 1980 outbreak has affected the industry's ability to replace necessary grow-out structures and related material. It has also affected industrial expansion in areas of Tomales Bay where considerable investments were being made to replenish stocks that had been depleted in recent years.

CONCLUSIONS

Paralytic shellfish poison represents a severe health problem to the public and an increasing threat to the commercial shellfish industry. Increased public education of the public sector would benefit both the agencies responsible for public health safety and the commercial industry. For the industry to survive major outbreaks, regulatory agencies with public health responsibility at all levels of government must take a greater responsibility in structuring news releases and working with media personnel. This must be done to assure that their own actions do not discredit the nonaffected products that the agencies have already certified as safe, or discredit products from nonaffected areas.

The 1980 California outbreak demonstrated the need for better monitoring programs. This is complicated by budget limitations, priorities, logistics, the need for a cheaper bioassay, and the development of accurate field monitoring test kits (Paralytic Shellfish Poison Management Workshop, 1982). Until these systems are fully developed, monitoring technology is still available, and monitoring programs should be more adequately supported for public safety. It is apparent from the 1980 California outbreak and previous outbreaks that annual quarantines, including posted notices and publicity, do not prevent poisoning and deaths associated with PSP. To effectively protect the public,

adequate monitoring activities in addition to the annual quarantines are necessary. State public-health agencies need to be better financed to cover the expense of monitoring programs. The commercial industry has a vested interest in supporting the establishment of adequate monitoring systems, but it should not be charged with the major financial responsibility of maintaining these programs. The major health hazard and problem primarily rests with sports-harvested shellfish, and commercial products have only been involved in two widely separated PSP incidents on the west coast. However, the shellfish industry can contribute financially by participating in cooperative monitoring programs by maintaining monitoring stations and providing samples of mussels and clams as well as oysters. These are expensive endeavors but can be incorporated into the work activities of the oyster companies. These are services beyond the financial capabilities of public health agencies and could serve as early warning for many sports-harvest areas. Preliminary cooperative arrangements have been made, and it is hoped that more equitable programs can be established.

A most critical recommendation is recognition that the impact of PSP is far beyond simple inability to market a product. Because of the nature of the west coast industry and its inability to reseed or maintain production integrity unless an adequate cash flow is maintained, a major PSP outbreak in a commercial producing area can have drastic effects on future production.

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REFERENCES

Beattie, J.H., McMillin, D., and Wiegardt, L., 1981. The Washington State Oyster Industry: A Brief Overview. World Mariculture Society, Proc. of the North American Oyster Workshop, Spec. Pub. No. 1, pp 28-38.

Chew, K.K., 1978. The Pacific Oyster (*Crassostrea gigas*) in the West Coast of the United States. In: R. Mann (Editor), *Symposiusm on Exotic Species in Mariculture.* MIT Press, Cambridge, Massachusetts, pp 54-82.

Conte, F.S. and Dupuy, J.L., 1981. The California Oyster Industry. World Mariculture Society, Proc. of the North American Oyster Workshop, Spec. Pub. No. 1, pp 43-63.

Dahlstrom, W., 1980. California Department of Fish and Game Memorandum to Johnson Oyster Company, 1 p.

Dressel, D.M. and FitzGibbons, D.S., 1978. The United States Molluscan Shellfish Industry. In: P.N. Kaul and C.J. Sinderman (Editors), *Drugs and Food From the Sea: Myth or Reality?* The University of Oklahoma Press, pp 251-261.

Fortuine, R., 1975. Paralytic Shellfish Poisoning in the North Pacific: Two Historical Accounts and Implications for Today. Alaska Medicine, 17(5):71-76.

Glude, J.B. and Chew, K.K., 1982. Shellfish Aquaculture in the Pacific Northwest. Proc. North Pacific Aquaculture Symposium, 1980, Anchorage. University of Alaska, Alaska Sea Grant Report 82-2, pp 291-304.

Khlebnikov, K., 1835. Life of Aleksandr Andreevich Baranov. General Manager of the Russian Colonies in America. In: *The Earliest History of Alaska.* Melvin, Cook Inlet Historical Society, Anchorage, 1970, 16 p.

Lutz, R.A. and Incze, L.S., 1979. The Impact of Toxic Dinoflagellate Blooms on the North American Shellfish Industry. Toxic Dinoflagellate Blooms. In: D.L. Taylor and H.H. Seliber (Editors), *Developments in Marine Biology, Volume I.* Elsevier North Holland, Inc., New York, pp 476-483.

Miescier, J., 1982. Paralytic Shellfish Poison Management Workshop, September 21-23, 1982. California Dept. of Health Services, U.S. Food and Drug Administration, Berkeley, California.

Paralytic Shellfish Poison Management Workshop, September 21-23, 1982. California Department of Health Services, U.S. Food and Drug Administration, Berkeley, California.

Qualman, J.L., 1981. Pacific Coast Region: Oregon's Oyster Industry. World Mariculture Society, Proc. of the North American Oyster Workshop, Spec. Pub. No. 1, pp 29-37.

Sharp, C.A., 1981. Paralytic Shellfish Poisoning: California-Summer 1980. California Department of Health Services, Sanitary Engineering Section (Department Report), 75 pp.

Shimizu, Y., 1982. Shellfish Aquaculture and Paralytic Shellfish Poisoning. Aquaculture: Public Health, Regulatory and Management Aspects. Proc. 6th U.S. Food and Drug Administration Scientific Symposium on Aquaculture. TAMU-SG-82-119, pp 38-48.

Span, J.A., 1978. Successful Reproduction of Giant Pacific Oysters in Humboldt and Tomales Bays, California. California Fish and Game, 64(2):123-124.

Vancouver, G., 1798. Voyage of Discovery to the North Pacific Ocean and Round the World. London, G.G. Robinson, J. Robinson, and J. Edwards. (Reprinted by N. Israel/Amsterdam, DaCapo Press/N.Y. Bibliotheca Australiana No. 30, 1967), Volume II, pp 282-286.

Verber, J.L., 1982. Shellfish-Borne Disease Outbreaks, FDA, Shellfish Sanitation Branch.