CONTRIBUTIONS
The Possible Relationship of El Niño/Southern Oscillation Events to Interannual Variation In *Gonyaulax* Populations as Shown by Records of Shellfish Toxicity

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Ecological studies of toxin-producing species of *Gonyaulax*, the dinoflagellates responsible for paralytic shellfish poisons (PSP) in shellfish, have indicated that water temperature and vertical stability of the water column are among the major factors governing development of dense populations of these species in both oceanic and embayment environments (C.M. Yentsch, pers. comm., 1982; Nishitani and Chew, 1984 and unpublished data). The relationship between high PSP levels in shellfish (indicating unusually dense *Gonyaulax* sp.) and weather conditions was pointed out by Waldichuck (1958), who attributed an occurrence of unusually high toxin levels to a prolonged period of higher than usual air temperatures, much reduced wind, and sunny weather following a period of abnormally high rainfall.

During tropical El Niño/Southern Oscillation (ENSO) events of a range of intensities (i.e., both strong events when an apparent northward intrusion of warm water occurs along the western coastline of North America and weaker events when such intrusion does not occur), a ridge of high atmospheric pressure develops over western Canada (Rasmusson and Wallace, 1983). The resultant effects on hydrographic conditions and weather, e.g., sea surface temperature (SST), sunshine and winds, hence, vertical stability of the water column, might be expected to enhance growth and accumulation of toxic *Gonyaulax* species(1). Very limited data are available on the extent and duration of blooms of *Gonyaulax* spp. in the Northeast Pacific. However, there are quite extensive records of PSP in shellfish, particularly along the coasts of Washington and British Columbia, and of human illness due to PSP, which provide an indirect measure of abundance of toxic *Gonyaulax* spp.

(1) Three closely related species of *Gonyaulax* are responsible for paralytic shellfish poisoning outbreaks along the northeast Pacific rim: *G. catenella*, *G. acatena*, and *G. tamarensis* (Taylor, 1984).
We sought to determine whether occurrences of PSP in shellfish are correlated with ENSO events and, thus, whether atmospheric and oceanographic anomalies induced by ENSO events would be useful in broad-scale prediction of PSP outbreaks along the coastline of British Columbia and Washington.

Findings

As a first approach we examined the degree of coincidence between ENSO events and exceptional episodes of PSP in Washington and British Columbia (Fig. 1). For this investigation, PSP episodes considered exceptional include outbreaks in geographical areas seldom or not previously affected by PSP, outbreaks with unusually
high PSP values for a given shellfish species (other than butter clams), and outbreaks (7 in Washington and 9 in British Columbia) in which the yearly highest level of PSP in butter clams within each jurisdiction was unusually high compared with adjacent years. (PSP data for butter clams are used because they are more complete than data for any other species.) The ENSO index, developed by Quinn, et al. (1978) to indicate intensity of events in the tropics, and occurrences of exceptional PSP episodes in Washington and British Columbia for 1942 and 1957-1984 are presented in Table 1. (Data for 1943-1956 are incomplete.)

The rationale for using exceptional PSP episodes is based on the fact that, because growth rates of Gonyaulax spp. are relatively slow, the development of a very dense population (hence, unusually high PSP in shellfish) requires that each of the many physical, chemical and biological factors governing its growth remains favorable for a prolonged period, often many weeks. Thus, occurrence of an exceptional PSP episode in a given year indicates that at one site, at least, the duration of favorable conditions was unusually prolonged.

Discussion

Exceptional PSP episodes occurred during all 9 of the ENSO events during the period of this study, i.e., in 13 of the 15 calendar years of those events. (Three of those 9 events had no second year.) Both the geographic distribution and the seasonality of occurrences of exceptional PSP during ENSO events suggest a correlation between the two kinds of events.

Exceptional PSP episodes were reported in both Washington and British Columbia in 7 of 9 ENSO events, often several hundred miles and several months apart, suggesting that conditions for growth of Gonyaulax may have been favorably affected by a widespread, long-term event. One such PSP outbreak caused deaths of humans, seabirds and perhaps fish in Washington and British Columbia in 1942 (see Table 1). A second example is the occurrence of high toxicity in butter clams, oysters and mussels in the Strait of Georgia during October, 1957 (the first such occurrence in that area), in oysters in a bay on the ocean coast of Washington in November and in razor clams on the adjacent ocean beaches the following June (the latter two episodes uncommon for that area, only 2 others having occurred in the following 26 years). When exceptional PSP occurred in years without ENSO events, it occurred in either Washington or British Columbia, not in both.

During ENSO events episodes of exceptional PSP in mussels, cockles, little neck and butter clams occurred during abnormal seasons, i.e., October-November in 4 of the 8 events with first year (EN1) data and May in 3 of 6 events with second years (EN2). (The normal growing season in inland waters in Washington is June-September.) These shifts in seasonality suggest continued growth in fall and earlier initiation of growth in spring. The latter would fit with the fact that the strongest connection between ENSO
### Table 1. ENSO events and episodes of exceptional PSP levels in shellfish.

<table>
<thead>
<tr>
<th>Year</th>
<th>ENSO Index</th>
<th>ENSO Year</th>
<th>Date</th>
<th>State/Prov.</th>
<th>Highest PSP in butter clams (µg/100g meat)</th>
<th>Unusually high PSP in other species or in unusual area</th>
</tr>
</thead>
<tbody>
<tr>
<td>1941</td>
<td>S E1N 2 (ENZ)</td>
<td>Nov.-Apr. BC</td>
<td>No PSP data available</td>
<td>Massive herring kill, S.E. Vancouver Is., possibly due to PSP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1942</td>
<td>S EN1</td>
<td>May 2 BC</td>
<td>Sea mussels =&gt; human deaths, W. Vancouver Is.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>May 2 WA</td>
<td>Mussels, clams =&gt; human deaths, Juan de Fuca Str.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Early May WA</td>
<td>Razor clams =&gt; pet deaths, ocean coast (uncommon)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nov. 8 BC</td>
<td>Unusual number of dead seabirds, ocean coast.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1957</td>
<td>S EN1</td>
<td>Oct. 24 BC</td>
<td>3174</td>
<td>Oysters, clams, mussels =&gt; human illness</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Nov. 8 WA</td>
<td>7706</td>
<td>1st PSP reported in Strait of Georgia</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>June 5 WA</td>
<td>867</td>
<td>Oysters, bays on ocean coast (uncommon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1961</td>
<td>- ---</td>
<td>Aug. 3 WA</td>
<td>2720</td>
<td>Razor clams, ocean coast (uncommon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1963</td>
<td>VW EN1</td>
<td>Nov. 18 BC</td>
<td>1760</td>
<td>Cockles =&gt; human death, Theodosia Inlet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1964</td>
<td>- ---</td>
<td>Aug. 26 BC</td>
<td>8640</td>
<td>Razor clams, open coast (uncommon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965</td>
<td>K EN1</td>
<td>May 31 BC</td>
<td>945</td>
<td>Little neck clams - 4000µg, oysters - 1900µg, W. Vancouver Is.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td>K EN1</td>
<td>Aug. 11 WA</td>
<td>1090</td>
<td>Mussels - 1200µg, Work Channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td>K EN2</td>
<td>May 4 BC</td>
<td>4200</td>
<td>Mussels - 30,000µg, 1st occurrence in Puget Sd.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>- ---</td>
<td>July 7 BC</td>
<td>4200</td>
<td>Razor clams, open coast (uncommon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972</td>
<td>S EN1</td>
<td>Sept. 5 WA</td>
<td>1090</td>
<td>Littleneck clams - 4000µg, oysters - 1900µg, W. Vancouver Is.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>S EN2</td>
<td>June 25 BC</td>
<td>945</td>
<td>Mussels - 1200µg, Work Channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1976</td>
<td>VW EN1</td>
<td>Oct. 13 WA</td>
<td>2220</td>
<td>Mussels - 30,000µg, 1st occurrence in Puget Sd.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>K EN2</td>
<td>May 31 BC</td>
<td>5100</td>
<td>Razor clams, open coast (uncommon)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1980</td>
<td>- ---</td>
<td>July 1 WA</td>
<td>2503</td>
<td>Mussels - 30,000µg, Work Channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1982</td>
<td>S EN1</td>
<td>June 1 BC</td>
<td>1090</td>
<td>Mussels - 30,000µg, Work Channel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1983</td>
<td>S EN2</td>
<td>June 18 WA</td>
<td>2503</td>
<td>Dysters - 2340µg, cockles - 1860µg, San Juan Is.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1984</td>
<td>(EN3)</td>
<td>June 27 WA</td>
<td>2503</td>
<td>Mussels - 30,000µg, Work Channel</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. S = strong; M = moderate; W = weak; VW = very weak [Quinn et al., 1978; Rasmussen and Wallace, 1983].
3. EN1 = first year of ENSO event; EN2 = second year of event.
4. Parentheses indicate that EN2 or EN3 year is not listed in references in 2 above.
5. Fisheries and Oceans Department, Canada, 1942-1984.
events and anomalous weather, including positive air temperature anomalies, in western Canada and the northwestern United States occurs during November (EN1) to March (EN2) (Horel and Wallace, 1981).

A further suggestion that a relationship between episodes of exceptional PSP and ENSO events stems from the recurrence of relatively high levels of PSP in oysters and/or razor clams along the ocean coast of Washington during strong ENSO events in 1942, 1957, 1958 and 1984, and in only one other year, 1970, the EN2 year of a weak ENSO event. Two of these 5 coastal PSP events fit the pattern of seasonal anomalies, i.e., during November (EN1) and May (EN2). The 1984 episode occurred in June. (Along the Washington coast the positive SST anomalies associated with the 1982-83 ENSO event continued through May, 1984 [National Weather Service, 1984]).

Exceptional PSP events also occurred in 6 of the 14 years without ENSO events. During 4 of these 6 (1961, 1978, 1980 and 1981) SST's were abnormally warm throughout the region (Hollister, 1964; Mearns, in preparation; Thomson, et al., 1984). Thus, at least one factor governing growth of *Gonyaulax*, SST, was similar during the exceptional PSP episodes in both ENSO and non-ENSO years, although the causes of the elevated SST's differed. An additional factor in 1978 was an exceptionally deep top layer of favorable temperatures resulting from abnormally heavy river runoff in the Whidbey Basin, the area first affected by extraordinary levels of PSP in that year (Water Resources Division, 1969-1978). Conditions contributing to the exceptional PSP episodes in 1964 and 1971 are not yet known. Five of the episodes of exceptional PSP during years without ENSO events occurred in July-September, the sixth in May, 1980. (A very weak ENSO event in 1979-80 was reported in the western Pacific [Donquy, et al., 1982]).

The lack of episodes of exceptional PSP during 2 of the 17 ENSO years (1973 and 1983) does not necessarily weaken the suggestion that the two kinds of events are related. It is not to be expected that PSP events as exceptional as those discussed in this study would occur in each year of each ENSO event. The associated oceanographic and atmospheric anomalies vary in degree and duration with different ENSO events. Further, during a year in which those anomalies permit a prolonged period of hydrographic and weather conditions favorable for *Gonyaulax* sp. in a given area, the period of continued growth might be cut short by a localized event such as strong tidal mixing or the occurrence of a dense predator population. The lack of exceptional PSP episodes during one of the ENSO years, 1973, may be attributable, in part, to the fact that weak negative SST anomalies occurred during that year (Thomson, et al., 1984). Conditions contributing to the lack in 1983 are not known.

Conclusions

The shellfish toxicity data thus strongly support the hypothesis that ENSO events of varying intensities may promote marked
increases in population densities of toxic Gonyaulax species in open coastal and inland waters along parts of the northeast Pacific Rim. Further study of SST's, and weather conditions (including atmospheric pressure, temperature, precipitation, insolation, wind direction and velocity) is being conducted to determine the strength of the correlation between anomalies in these variables, induced by ENSO events or by other factors, and high PSP levels in the shellfish.

If a strong correlation can be shown, weather conditions and SST's might be useful in broad-scale prediction of periods of dense Gonyaulax populations and high risk of hazardous PSP levels in shellfish. Two additional biological responses to ENSO events and other warm periods might be expected. The introduction of increased quantities of PSP into the food web, via a variety of filter feeders, would increase the potential for higher mortality in a great diversity of animal species, including finfish, seabirds and marine mammals. In addition, more widespread shifts from diatom to dinoflagellate dominance than indicated by PSP records could occur during ENSO events since many species of dinoflagellates grow and accumulate under physical conditions similar to those promoting blooms of Gonyaulax sp. To the extent that this shift occurs, particularly at unseasonable periods, it may be one of many factors contributing to anomalies in population densities or geographic distribution of species at all trophic levels. The extent of these two broad types of effects, whether in small bays or over a larger segment of the coastal waters, would depend on the magnitude of the oceanic and atmospheric anomalies caused by the ENSO event.

Acknowledgments

This work was supported, in part, by College of Ocean and Fishery Sciences Select Programs and Washington Sea Grant Program. We would like to thank the following people for their comments and suggestions: John Liston, Kenneth Chew, Lewis Incze, Joyce Lewin, Amy Schoener and Lee Wiegardt. Rudy Chiang and Laura Kentala kindly supplied PSP data.

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References


Seawater Temperature, Sea Level, and Ekman Transport along the Coast of British Columbia During the 1982–83 El Niño

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Introduction

The effects of the 1982-83 El Niño on the waters along the coast of British Columbia were manifested by the large positive anomalies in sea surface temperature, sea level and Ekman transport. These data are presented for 1982-83 and compared to those for the El Niño years of 1941 and 1958 for selected locations along the coast of British Columbia (Fig. 1). Bottom-water temperatures on the continental shelf are presented for May 1977-83.

Annual Sea Surface Temperature Anomalies

In 1983, large positive annual sea surface temperature anomalies (annual mean minus long-term annual mean) were observed at Amphitrite Point and Kains Island (Fig. 2). The anomalies were similar to those observed in 1941, but larger than observed in 1958 at these locations.

Monthly Sea Surface Temperature Anomalies

Monthly sea surface temperature anomalies (monthly mean minus long-term monthly mean) at British Columbia shore stations were generally small and variable throughout most of 1982 (Fig. 3). By December, slightly above-average sea surface temperatures prevailed; a marked increase in the anomalies occurred in January. They continued to increase and, in most cases, peaked in March-April to values as great as 2.5°C. A decrease in the monthly anomalies occurred from May to June at the stations presented except in the north at Langara Island. At those stations showing a decrease, there was a lower-than-average increase in the monthly means from May to June. This is attributed mainly to below-average local heating in June. An increase in anomalies generally occurred from June to July, except at Cape St. James and Entrance Island. The notable exception was at Entrance Island in the Strait of Georgia where a negative anomaly was observed. After July, the anomalies decreased. During the latter part of the year, near-average temperature conditions are indicated.
Figure 1. Map showing locations of British Columbia lightstations and sea-level recording stations (open circles) and grid points for calculations of Ekman transport (solid circles) referred to in the text.

Figure 2. Annual sea surface temperature anomalies (°C) at Amphitrite Point and Kains Island, Vancouver Island, 1935-83.
The monthly sea surface temperature anomaly patterns for 1941 and 1983 were somewhat similar in that the largest anomalies generally prevailed in late winter and spring (Fig. 4). However, in 1958, the anomalies were generally largest in spring and summer. During the last 4 months of the year, anomalies were generally larger in 1941 than in 1958. In 1958, the anomaly appeared to be earlier progressing northward. The reverse would be expected if advection was the dominant process.
Figure 4. Monthly sea surface temperature anomalies (°C) at selected British Columbia lightstations, 1941, 1958 and 1983.

Monthly Sea Level Anomalies

Monthly mean sea level anomalies were relatively large during the latter part of 1982 at Tofino and Prince Rupert (Fig. 5). A marked increase in the sea level anomalies occurred in January, and they remained relatively large through March. The anomaly decreased markedly in April. Thereafter, the anomalies generally increased to a maximum in July, and then decreased. Anomalies at Prince Rupert were larger than those at Tofino during the spring-early autumn period.
Figure 5. Monthly sea level anomalies (cm) at Tofino, B.C. and Prince Rupert, B.C. and monthly mean Ekman transport (open bars) and anomalies (solid bars) normal to the coast (cu cm/sec/100 m of coastline), 1941, 1958 and 1982-83. Sea-level anomalies were derived from unadjusted values of sea level. Transport values are from National Marine Fisheries Service, Monterey CA but the signs have been reversed; onshore transport is positive and offshore transport is negative.

Ekman Transport

Onshore-offshore transports normal to the coast indicate the relative persistence and strengths of the convergent-divergent processes. At these latitudes, the convergent condition is the strongest and more persistent of the two processes.

During October-December 1982, monthly mean anomalies indicate
Table 1. Mean bottom-water temperatures (°C) by depth interval (m) of the continental shelf waters between Amphitrite Point and Estevan Point, Vancouver Island, May 1977-83.

<table>
<thead>
<tr>
<th>Depth Interval (m)</th>
<th>Range (°C)</th>
<th>Mean (°C)</th>
<th>Δ T°</th>
<th>Min/Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>48-71</td>
<td>10.5-10.7</td>
<td>10.6(3)</td>
<td>8.7(1)</td>
<td>-</td>
</tr>
<tr>
<td>72-90</td>
<td>9.5-10.4</td>
<td>10.0(4)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>91-108</td>
<td>8.6-8.7</td>
<td>8.6(2)</td>
<td>8.0(2)</td>
<td>8.0(6)</td>
</tr>
<tr>
<td>109-126</td>
<td>8.2-9.1</td>
<td>8.6(6)</td>
<td>7.7(6)</td>
<td>7.5(7)</td>
</tr>
<tr>
<td>127-149</td>
<td>7.8-8.4</td>
<td>8.1(11)</td>
<td>7.5(7)</td>
<td>7.3(5)</td>
</tr>
<tr>
<td>146-163</td>
<td>7.7-8.0</td>
<td>7.8(10)</td>
<td>6.9(1)</td>
<td>7.2(12)</td>
</tr>
<tr>
<td>164-181</td>
<td>-</td>
<td>7.8(3)</td>
<td>-</td>
<td>6.9(2)</td>
</tr>
<tr>
<td>182-200</td>
<td>7.8-7.9</td>
<td>7.9(3)</td>
<td>7.3(1)</td>
<td>-</td>
</tr>
</tbody>
</table>

Numbers in brackets indicate number of observations
*Δ T° = Minimum and maximum differences between 1983 and 1977-82 values

relatively small to average onshore transport, but anomalously large onshore transport in January-March 1983 (Fig. 5). During the latter period, a strong convergent condition is indicated. Under this condition, a strong northerly flow and high sea-surface to bottom temperature over the continental shelf are indicated. In May 1983, offshore transport was relatively large at the southern grid part for this period, reflecting a relatively strong divergent condition for, at least the southern coast. In June-August, offshore transport was relatively small (June-July) to average (August), indicating a relaxation to a weak divergent condition. In contrast, offshore transport was anomalously large in July-August 1958, particularly in July. No data are available for 1941 for comparison.

Mean Bottom-water Temperatures

In May 1983, mean bottom-water temperatures on the continental shelf off central Vancouver Island were high compared to those of the six previous years (1977-82) (Table 1). Positive anomalies of between 0.4-1.5°C were observed.
BIBLIOGRAPHY AND APPENDICES
Bibliography of Niño Effects in the Eastern Subarctic Pacific

Compiled by Erik Stockdale

In bringing together the material in this volume, we ran across many publications dealing with Niño events in the eastern subarctic Pacific. They are listed here if they deal explicitly with observations or analyses associated with Niño events in the region. While the list is not comprehensive, when used with the papers in this volume, it can introduce the reader to much of the published information on the phenomenon as it appears in this region.

The Editors


APPENDIX A  Program
A Meeting on Nino Effects in the
Eastern Subarctic Pacific

12-13 September 1984, 0830-1630, Pacific Marine Environmental Labora-
tory, Sand Point, Seattle. Sponsored by International Recruitment
Investigations in the Subarctic, IRIS, and supported by Northwest
and Alaska Fisheries Center of NMFS.


Introduction. W.S. Wooster, UW.

Ocean response during El Nino events. B. Taft, PMEL.

Atmospheric response to equatorial sea-surface temperature
anomalies. J.M. Wallace, UW.

Atmospheric forcing of interannual variability in the northeast
Pacific. K. Hamilton, UBC.

The 1982-83 El Nino in the eastern tropical Pacific. D. Halpern,
PMEL. *

Nino effects in Kuroshio and western north Pacific. M. Kawabe,
U. Tokyo.

The 1982-83 El Nino event off Baja and Alta California. J. Norton,
D. McLain, D. Busby and R. Brainard, PEG.

The apparition of El Nino off Oregon: 1982-83. A. Huyer and
R.L. Smith, OSU.

Comparison of El Nino effects off the Pacific Northwest. G. Cannon,
R. Reed and P. Pullen, PMEL.

El Nino effects off the Pacific coast of Canada, 1982-83.
S. Tabata, IOS.

Comments on interannual variability of northeast Pacific eddies.
L. Mysak, UBC.

* manuscript not available at time of publication.


THE BIOLOGICAL RESPONSE. 13 September 1984

El Nino and plankton productivity. R. Barber, Duke. *

Case history of a transition from anti-El Nino to El Nino: effects on plankton and nekton distributions and abundance. P. Smith, SWFC.

The effects of El Nino events on the early life history and recruitment of subarctic marine fish and shellfish. K. Bailey and L. Incze, NWAFSC.

Structural changes in the California Current ecosystem during 1983. J. McCowan, SIO.

Changes in Oregon plankton and larval fishes during the northern El Nino of 1983. C. Miller, H. Batchelder, R. Brodeur, and W. Pearcy, OSU.


Effects of the 1982-83 El Nino on reproduction of six species of seabirds in Oregon. M.R. Graybill, J. Hodder, UOR.

Inter-Nino comparisons in the marine ecosystems off Washington. A. Schoener, NWAFSC and D. Fluharty, UW.

Salmon management in response to the 1982-83 Nino event. M. Hayes, and K. Henry, NWAFSC.

(1) Summary of biological, physical and chemical observations in British Columbia waters during the 1982-83 El Nino; (2) Interannual shifting of the Pacific Subarctic boundary on the west coast of North America from 1956 to 1964 as indicated by zooplankton biomass. J. Fulton, R.J. LeBesseur, PBS.

Patterns of phytoplankton nutrient utilization and their dependence on physical processes in the Bering Sea. R.N. Sambrotto, UArk.

* manuscript not available at time of publication.
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