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8. This work was supported by the Office of Naval Research (NOO-14-66 contract CO-241) and the National Science Foundation (grant DES 74-22781). Contribution Number 3673 of the Woods Hole Oceanographic Institution.

1 December 1975; revised 13 August 1976

Biological Consequences of the 1975 El Niño

Abstract. *The weak El Niño event of 1975 had a clearly defined effect on the biological productivity of the southeastern tropical Pacific. During February and March 1975, warm (27°C) water of low salinity (33.5 parts per thousand) and low nutrient content extended south across the equator east of the Galápagos Islands, replacing the nutrient-rich water normally supplied by equatorial upwelling. Equatorial primary production was less than 0.2 gram of carbon per square meter per day, one-fifth of the normal value. At the maximum development of the 1975 event, the coastal region of Peru continued to have strong nearshore upwelling with primary production values greater than 2.5 grams of carbon per square meter per day, although the zone of high production was confined to a 250-kilometer-wide band, one-half its normal width. The biological effects of the 1975 event were short-lived; in April and May 1975 the equatorial region had begun to reestablish its normal levels of primary production.*

El Niño conditions are characterized by invasions of anomalously warm, nutrient-depleted water into the coastal regions of Ecuador and Peru. Under normal conditions these coastal waters are strongly influenced by the cold, nutrient-rich water that reaches the surface by coastal upwelling. This water supports high primary production and the world's largest anchovy fishery. Onset of severe El Niño conditions usually has disastrous effects on the yield from this fishery.

Quinn (*1*) predicted that "weak" El Niño conditions would develop in the eastern tropical Pacific during the early months of 1975. Wyrtki *et al.* (*2*) presented the physical features of the observed El Niño conditions, which occurred as predicted. East of the Galápagos Islands, in February and March 1975, warm (27°C), low-salinity [33.5 parts per thousand (ppt)] water extended south across the equator as far as 4°S, and the Galápagos Equatorial Front was almost 500 km south of its usual position. Severe reductions in offshore primary production were also observed in February and March, although primary production along the coast of Peru was comparable to normal, non–El Niño conditions. In this report we describe the observed primary production during and after the 1975 El Niño in the equatorial and coastal upwelling regions and comment on the potential influence of the 1975 event on the Peruvian anchovy.

The data reported here were collected during two successive cruises (11 February to 31 March and 17 April to 27 May) of the R.V. *Moana Wave* along the cruise track shown in Fig. 1A (*3*). Primary production was measured by the modified carbon-14 method of Steeman-Nielsen [(*4*); see also (*5*)], with samples incubated for 24 hours under natural light in neutral-density filters, which simulate light intensity at the depths of sample collection (depths at which incident radiation was 100, 50, 25, 10, and 1 percent of surface radiation). Productivity values were then integrated over the depth of the euphotic zone. The data are expressed as grams of carbon assimilated per square meter of ocean surface per day. Nutrients were analyzed with a modified Technicon AutoAnalyzer II, and data are reported in micromoles per kilogram of seawater.

Table 1. Dominant phytoplankton in the coastal surface waters of Peru in March and April 1966 and February and March 1975. Values for 1966 are from Ryther *et al.* [table 1 in (*11*)]; those for 1975 are mean values for two coastal stations (ranges are given in parentheses).

Species	Abundance (cell/ml) 1966	Abundance (cell/ml) 1975
Asterionella japonica	21	22 (0–45)
Chaetoceros compressus		62 (0–123)
Chaetoceros curvisetus		68 (62–73)
Chaetoceros debilis	312	
Chaetoceros lorenzianus	67	42 (0–84)
Chaetoceros socialis	26	308 (168–448)
Leptocylindrus danicus		65 (6–123)
Nitzschia delicatissima	2	11 (6–17)
Nitzschia seriata	22	
Schroederella delicatula	12	146 (84–207)
Skeletonema costatum	4	247 (34–459)
Thalassiosira sp.		879 (868–890)
Coccolithus huxleyi	2	

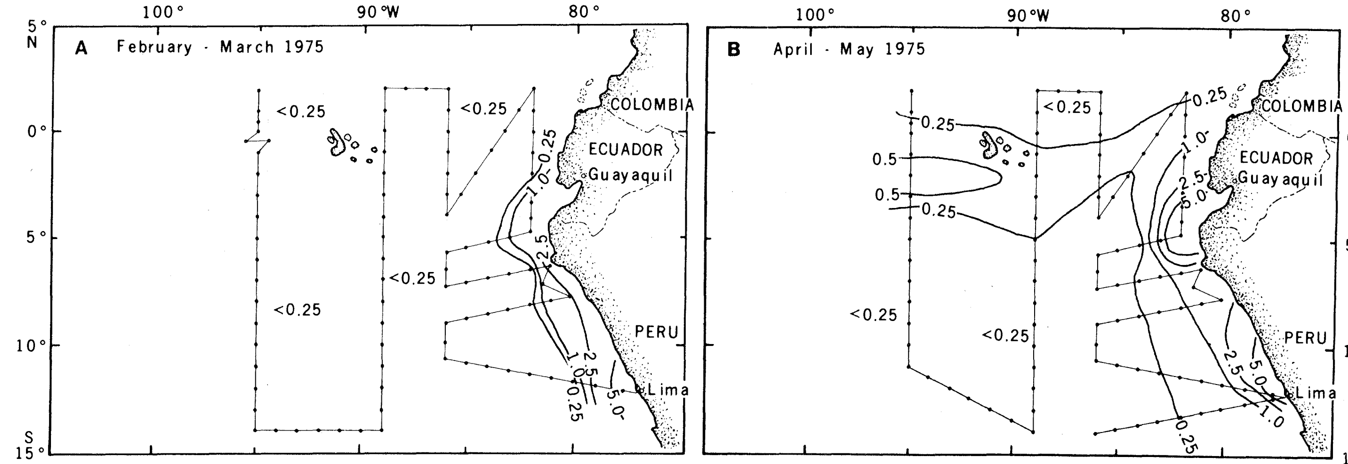
Wyrtki *et al.* (*2*) discussed the intrusion of warm, low-salinity water (27°C, less than 33 ppt) across the equator east of the Galápagos Islands. The normal pattern of equatorial primary production was drastically altered by this warm-water intrusion (Fig. 1A). During the February-March interval, only one station in the equatorial zone had production greater than 0.25 g m^{-2} day^{-1}, while most stations had productivity values an order of magnitude lower than normal (Fig. 1C).

Primary production values in the Peruvian coastal region were as high as normal ones in February and March 1975 (Fig. 1, A and C), but the productivity was confined to a narrower zone than in the non–El Niño years for which we have data. In February and March 1975, the contour representing 0.5 g m^{-2} day^{-1} was no farther than 250 km from the coast, while the same contour extended 500 km from the coast in 1968 (*6*). In 1966, all the productivity measurements within 250 km of the coast were greater than 1.0 g m^{-2} day^{-1}.

Equatorial primary production returned to near-normal levels during April and May 1975, as seen in Fig. 1B. The 0.5 g m^{-2} day^{-1} contour extended 400 km off the coast, and primary production increased two- to fivefold across the equatorial region.

Results from previous oceanographic expeditions to the southeastern tropical Pacific have established the pattern of primary production in non–El Niño years. Figure 1C shows contours of primary production from cruises in 1966 and 1968 (*7*). Note the wide band of higher production along the equator west of the Galápagos Islands. Owen and Zeitzschel (*6*) reported similar results from a survey of a larger region of the eastern tropical Pacific. They found that integrated production values along the equatorial zone ranged from 0.3 to 0.5 g m^{-2} day^{-1} in February and March 1968 [see figure 1 in (*6*)] west of the Galápagos.

It is not clear what factors were limiting primary production in the offshore, nonequatorial region south of the Galápagos and west of Peru during the 1975 El Niño conditions. Nutrients were present in excess in the surface waters (NO_3^- greater than 5.0 μmole/kg), yet the small standing stock of phytoplankton showed



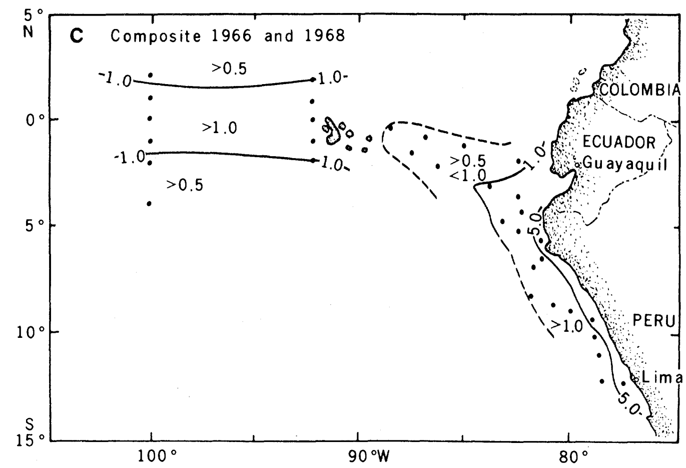
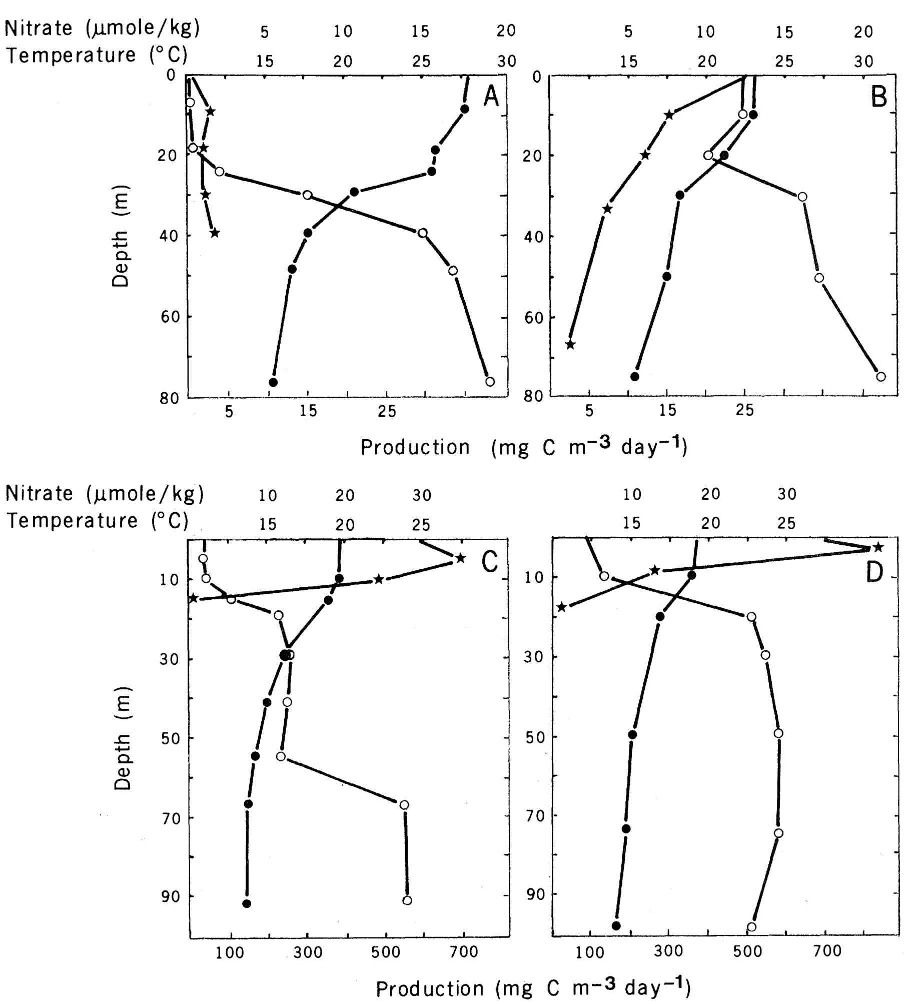


Fig. 1 (left and above). Distribution of primary productivity in the eastern tropical Pacific (A) at the peak of the 1975 El Niño, (B) later in 1975 when normal conditions were reestablished, and (C) in the same region during 1966 and 1968, when no indication of an El Niño–type disturbance was present. Data contoured are depth-integrated primary production in grams of carbon per square meter per day. Data contoured in (A) and (B) were collected aboard the R.V. *Moana Wave*; data contoured in (C) are composite from data collected aboard the R.V. *Te Vega* and R.V. *Anton Bruun*. Fig. 2 (below left). Vertical profiles of temperature, nitrate concentration, and primary production in 1975 and 1966, illustrating the magnitude of the disturbance in equatorial regions in 1975 and the lack of disturbance in the Peruvian coastal region. Equatorial stations: (A) 2°S, 86°W on 6 March 1975, and (B) 2°19′S, 86°6′W on 14 April 1966. Coastal stations: (C) 12°44′S, 77°45′W on 31 March 1975, and (D) 12°6′S, 78°8′W on 5 April 1966. The data graphed are (●) temperature, (○) nitrate concentration, and (★) primary production.



little production. Barber and Ryther (*8*) reported inhibition of phytoplankton growth in equatorial waters due to a lack of organic chelators. Another explanation for low measured primary production is intense grazing by herbivores, maintaining phytoplankton biomass at low levels (*9*).

The striking hydrographic and biological effects of the 1975 event are seen by comparing vertical profiles of the 1975 and 1966 equatorial conditions (Fig. 2, A and B, respectively). In February and March 1975, surface equatorial waters were 4°C warmer than in 1966, with more stratification of the water column. The low primary production illustrated in Fig. 2A was typical for the 15 equatorial stations occupied during February and March 1975, where surface waters were depleted in nutrients (NO_3^- less than 1.0 µmole/kg) at 10 of these 15 stations. The 1966 conditions shown in Fig. 2B provide a striking contrast to the situation in February and March 1975. The poorly defined thermocline resulted in vertical exchange of nutrients with the surface waters, with concomitant increased primary production.

A comparison of vertical distributions of properties in the Peruvian coastal region emphasizes that the 1975 event had no effect there. Figure 2, C and D, shows that the hydrography and primary production in early 1975 were essentially the same as in 1966. Data for two stations within 250 km of the coast, together with the data shown in Fig. 1, suggest that the 1975 El Niño conditions limited the offshore extent of the coastal zone of production, but did not affect the magnitude of production within the compressed coastal zone.

As discussed by Wyrtki *et al.* (2), by late April 1975 conditions in the equatorial zone of the eastern tropical Pacific were rapidly returning to normal. Cool, nutrient-rich water was present at the surface at all but four equatorial stations, with up to fivefold increases in primary production. Vertical profiles of the equatorial conditions in late April and early May are similar to Fig. 2B, which emphasizes the short duration of the 1975 El Niño–like event.

The environmental conditions that result in increases or decreases of important fish stocks have not been well established, but Lasker (*10*) has shown that anchovy larval survival is dependent on the availability of phytoplankton cells of the proper size above a critical concentration, and he has been able to relate the population size of fish born in a particular year to the observed quantity and quality of phytoplankton food. Although Lasker's exciting information is based on the northern anchovy, *Engralis mordax*, found off the west coast of North America, it is reasonable to expect a similar mechanism for the Peruvian anchovy, *Engralis ringens*, whose overall biology is similar. If survival of the year's population depends on having a high concentration of the right kind of phytoplankton, it appears that the 1975 event would have no detrimental effect on the anchovy, because the conditions for normal high primary production persisted throughout the coastal region even at the maximal development of the 1975 event in February and March. Table 1 is a list of the dominant phytoplankton species present in coastal surface waters in 1966 and 1975 (*11*). If the phytoplankton conditions necessary for survival were provided by the conditions prevailing in 1966 and 1968, our data indicate that they were also provided by the conditions prevailing in 1975. The 1975 event, while it affected a large area of the southeastern tropical Pacific, did not change the character of the coastal upwelling zone off Peru.

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2 August 1976; revised 21 September 1976

Energetic Radiation Belt Electron Precipitation: A Natural Depletion Mechanism for Stratospheric Ozone

Abstract. *During geomagnetically disturbed periods the precipitational loss of energetic electrons from the outer radiation belt of the earth can readily provide the major ionization source for the mesosphere and upper stratosphere. One particularly intense manifestation of this interaction between the radiation belts and the lower atmosphere is the relativistic electron precipitation (REP) event which occurs at subauroral latitudes during magnetospheric substorm activity. At relativistic energies the precipitating electrons produce copious fluxes of energetic bremsstrahlung x-rays, the major portion of which penetrate deep into the stratosphere before undergoing excitation and ionization collisions with the neutral atmosphere. If such REP events occur more than a few percent of the time, they can, on an annual basis, provide a local source of upper stratospheric nitric oxide molecules (via the dissociation of molecular nitrogen) comparable to that from either galactic cosmic rays or energetic solar proton events. Since nitric oxide plays a major role in the removal of stratospheric ozone, it appears that the influence of REP events must also be considered in future photochemical modeling of the terrestrial ozone layer.*

It is now well established that the direct removal process for stratospheric O_3 first proposed by Chapman (*1*)

$$O + O_3 \rightarrow 2O_2$$

can explain only 20 percent of the loss rate needed to balance photochemical production (*2*). Catalytic reactions with water compounds (hydroxyl radicals) probably account for an additional 10 percent of the required O_3 removal rate. The most acceptable mechanism for the bulk (70 percent) of O_3 destruction involves catalytic reactions with oxides of nitrogen (NO_x) (*3*):

$$NO + O_3 \rightarrow NO_2 + O_2$$
$$NO_2 + O \rightarrow NO + O_2$$

The precise role played by other catalytic agents [such as atomic chlorine (*4*)] remains controversial, but it is probably fair to conclude that these are not as important as NO_x.

The principal source of NO in the lower stratosphere (below 30 km) is from the upward diffusion and subsequent oxidation of tropospheric N_2O by excited oxygen [$O(^1D)$] atoms (*3*); NO is also produced directly throughout the stratosphere by energetic particle precipitation. The primary particles produce an intense flux of secondary electrons (with an energy of 10 to 100 ev) which readily dissociate N_2; the atomic nitrogen subsequently recombines with O_2 to yield NO and atomic oxygen. Current estimates suggest that the rate of NO production is comparable (within a factor of 2) to that of ion pair production (*5–7*). The detailed knowledge gained from studies of precipitation-induced ionization of the lower atmosphere (*8*) can therefore be used to estimate the altitude profile of NO production (and subsequent O_3 removal) during certain types of particle precipitation.

Several examples of energetic ion precipitation and their potential role in modifying stratospheric O_3 have already been