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Central Pacific Seabirds and the El Niño Southern Oscillation: 1982 to 1983 Perspectives

Abstract. *The breeding chronology and reproductive attempts of the seabird community on Christmas Island in the central Pacific Ocean (2°N, 157°W) were interrupted by the 1982–1983 El Niño Southern Oscillation. The resultant reproductive failure and disappearance of the entire seabird community of this equatorial atoll represents the most dramatic interruption on record of a seabird community located distant from coastal upwelling. Our data indicate the effect that the abiotic and biotic aspects of a global atmospheric-oceanic anomaly have on marine birds. The 1982–1983 El Niño Southern Oscillation provides an example of selective pressures and a natural experiment in the study of vertebrate population dynamics.*

El Niño is the periodic appearance of anomalous warm water in the eastern Pacific Ocean off the coasts of Ecuador and Peru, a geographically restricted phenomenon that is a highly visible part of a major warming of the entire eastern equatorial Pacific Ocean in response to atmospheric forcing known as the Southern Oscillation. While causative agents remain unknown, the meteorological and physical oceanographic results of El Niño Southern Oscillations (ENSO's) are reasonably well understood (*1*). The biological consequences are less well known (*2*), although seabirds along the west coast of South America are known to be affected during ENSO's (*3*). We now report our observations of ENSO effects on seabirds from the central Pacific Ocean.

The breeding biology characteristics of seabirds (one large egg, long incubation period, extended parental care, post-fledging feeding of juveniles, deferred maturity, long life-span) are generally assumed to indicate dependence of these pelagic foragers on a distant, limited, or ephemeral food supply of small fish and squid. Seabirds are, to a large extent, dependent on predator fishes and marine mammals to drive smaller fishes and squid toward the ocean surface. Populations of seabirds are thought to be restricted by low food availability in these pelagic feeding zones (*4, 5*). Our data on the seabird community of Christmas Island in the central Pacific Ocean (2°N, 157°W) collected before the 1982–1983 ENSO and combined with studies that were conducted for 1 year after the onset of these anomalous ocean-atmosphere interactions provide insight into how abiotic conditions affect the upper levels of the marine ecosystem.

Data for Christmas Island collected from the 1940's through June 1982 revealed no total reproductive failure of any species during previous ENSO's, provided reasonable estimates of the populations for each species, illustrated breeding seasons, and documented the species' diet. Many species breed at any time of year, but nearly all show distinct seasonal variations in amounts of laying with a variety of patterns of breeding between species, and fishes and squid are the primary food items (*6*). On a visit to the island in November 1982, we discovered a total reproductive failure of all species present and a virtual disappearance of all individuals from the atoll (Table 1). Periodic visits since then have revealed a drastic decrease in populations of most species and alterations in reproductive effort (Figure 1, Table 2).

Shearwaters and petrels are all ground or burrow nesters and thus are highly susceptible to flooding. In the fall of 1982 a few Phoenix petrels (*Pterodroma alba*) and Christmas shearwaters (*Puffinus nativitatis*) were courting, but no successful reproduction occurred. By June 1983, these birds along with wedge-tailed shearwaters (*Puffinus pacificus*) were present in low numbers, and some limited reproduction occurred. Audubon's shearwaters (*Puffinus lherminieri*), absent from the atoll for at least a year, and white-throated storm petrels (*Nesofregetta albigularis*), absent during the winter of 1982, began to return in the fall of 1983.

Early nesting red-tailed tropic birds (*Phaethon rubricauda*) were not affected in the summer of 1982, but late nesters were totally unsuccessful. Numbers of late nesters were low in June 1983 but increased, with large numbers of healthy young present in October 1983. Masked boobies (*Sula dactylatra*) were nesting in June 1982 in normal numbers, with eggs or small young present. In view of the 45-day incubation period and the 4-month nestling period, large numbers of preflying nestlings and adults should have been present in November 1982; however, we found only one 4-month-old nestling and three adults. The fully feathered nestling's weight (1250 g) was about 25 percent below normal for its age. We saw few adults and no juveniles elsewhere on the atoll in November, an unusual absence. In June 1983 no eggs were present, but by October there were many adults with eggs and healthy nestlings. Brown boobies (*Sula leucogaster*) all failed in nesting attempts in November 1982. In June 1983 some eggs had been laid, but these did not produce young, and by October few adults were present. In November 1982 we found no red-footed booby (*Sula sula*) nests and only a couple hundred roosting birds when thousands normally are present. During May and June numbers of adults had increased, and some were nesting. No juveniles were present. In October about 20 percent of normal nests were present with eggs and healthy nestlings of various ages, and many juveniles had fledged.

Great frigate birds (*Fregata minor*) nested in large numbers (~8000) in June 1982. In November we saw fewer than 100 birds during our stay on the atoll. Approximately 90 nestlings should have been present in our study colonies, but we found only six still alive, none of which was able to fly and all were starving. Also, we found 19 fully feathered carcasses lying on their nests where they had died. All other nests were either empty or had been destroyed by rain. Thus reproductive success for great frigates was zero in 1982. We estimated 3500 pairs of lesser frigate birds (*Fregata ariel*) with eggs or small young in June 1982. In November we found hundreds of dead nestlings. Perhaps 300 young had fledged and fewer than 50 adults were present. The 12 nestlings we weighed were significantly under weight for their size. In June 1983 we estimated that approximately 4000 pairs were present, all actively courting or with eggs. In October many healthy young were present.

We expected to find large numbers of sooty terns (*Sterna fuscata*) swirling over nesting locations at night in November 1982 in preparation for the December-January laying season. We neither saw nor heard any sooties in late November, and none nested that season. In June 1983 about 1 percent of their normal population had returned, and eggs and small young were present. The laying period was extended beyond its usual term, and healthy fledglings were present in one colony in October 1983; however, in another colony about 65 km away (on Cook Islet) about 5000 young starved just before fledging. Gray-backed terns (*Sterna lunata*) were pres-

Table 1. Seabird populations on Christmas Island in November 1982, during the 1982–1983 El Niño Southern Oscillation. Censuses of the total breeding population of seabirds occupying the atoll are impossible to make because of the size of the island and the extended breeding seasons of most species. These data represent a best estimate on the basis of pre-November 1982 data for use in comparison to November 1982 through October 1983 surveys (see Table 2). Numbers represent the total population occupying the island during a given year. All individuals of the species observed during this period failed except for small numbers of surviving lesser frigate birds, brown and black noddies, and white terns.

Species	Normal number of pairs	Expected	Observed
Phoenix petrel	12,000	Nesting	Courtship
Wedge-tailed shearwater	500,000	None	None
Christmas shearwater	6,000	Nesting	Courtship
Audubon's shearwater	1,000	Nesting	Starving chicks
White-throated storm petrel	500	Nesting	None
Red-tailed tropic bird	4,000	Nesting	A few chicks
Masked booby	1,500	Nests, fledglings	None
Brown booby	300	Nesting	A few nests
Red-footed booby	6,000	Nesting	A few adults
Great frigate bird	6,000	Nesting	Dead chicks
Lesser frigate bird	4,500	Nesting	Dead chicks
Sooty tern	3 million to 4 million	Courtship	None
Gray-backed tern	3,000	Present	Present
Crested tern	350	Present	Present
Blue-gray noddy	2,000	Nests	Few, no nests
Brown noddy	3,000	Nesting	A few nests
Black noddy	10,000	Present	All nests gone
White tern	4,000	Nesting	Few adults

Table 2. Seabird populations on Christmas Island during and after the 1982–1983 ENSO. Numbers compared to normal (see Table 1) are estimates of the percentage of numbers expected on the basis of data collected during earlier surveys (May–June and October) (*6*). Some species may normally be absent or present only in small numbers at any given season.

Species	May–June 1983		October 1983	
	Numbers compared to normal (%)	Breeding cycle	Numbers compared to normal (%)	Breeding cycle
Phoenix petrel	Low (20)	Some nesting, eggs	Increasing (50)	Courtship, a few eggs
Wedge-tailed shearwater	Low (25)	Some nesting, eggs	Normal	Many healthy chicks
Christmas shearwater	Low (20)	Some nesting, eggs	Low (50)	Courtship
Audubon's shearwater	Not present		None seen	
White-throated storm-petrel	Not present		Increasing (30)	Eggs
Red-tailed tropic bird	Low (10)	Nesting, eggs	(90–100)	Healthy chicks
Masked booby	Low (1–2)	A few eggs, adults roosting	(50-60), roosting	Eggs, healthy chicks to 3 months old
Brown booby	Normal	Eggs, chicks (all fail)	(5–10)	No nesting
Red-footed booby	Low (30)	Nests, eggs, chicks; no juveniles	Increasing (60)	Many juveniles, eggs, chicks
Great frigate bird	Low (1–2)	A few eggs	(10–15)	A few healthy chicks
Lesser frigate bird	Increasing (60)	Eggs, small chicks	Normal	Many chicks, juveniles
Sooty tern	Low (1)	Eggs, chicks	Few (2–4)	Some fledglings; high chick mortality; some courtship
Gray-backed tern	Low (5)	No nesting	None seen	
Crested tern	Normal	Chicks	Present	Juveniles present
Blue-gray noddy	Low (5)	No nesting	(10–20)	Some eggs, chicks
Brown noddy	Low (10–15)	Eggs	Few (10–20)	
Black noddy	Normal	Roosting, eggs, chicks	Few expected	No nesting; many dead chicks
White tern	Low (10–15)	A few eggs	Many (120)	Many eggs, chicks

ent in November 1982 in normal numbers, but no nesting occurred between then and October 1983, and few adults were present during 1983. Crested terns (*Thalasseus bergii*) roosted in their usual numbers in November 1982, and they nested successfully from April to June 1983 and were present in October. Blue-gray noddies (*Procelsterna cerulea*) should have been present in large numbers in November 1982, but we found few, and their numbers remained low from May to June and in October 1983, when a few pairs had eggs. Brown noddies (*Anous stolidus*) were mostly absent from the atoll in November 1982, and their numbers remained low through 1983, with limited reproduction from June to October. All nests of black noddies (*Anous minutus*) were washed out of trees by November 1982, and few adults were seen, but normal numbers of adults and nests were present in June 1983. In October 1983 large numbers of skeletons of young were found in nests, indicating a major reproductive failure from July to August 1983. White terns (*Gygis alba*) were totally unsuccessful in November 1982, and few were present in June 1983. By October large numbers of eggs and healthy young were present.

The oceanic and climatological conditions in the Pacific region during the 1982–1983 ENSO have been summarized (*1*), and those specific for Christmas Island and of direct relevance to seabirds are presented in Fig. 1 (*7*). Also, the ocean currents and thermocline were unusual from July to August 1982 and from May to July 1983 (*8*). The high sea level accompanying the heavy rains caused extensive flooding from October 1982 through May 1983. We believe adult birds of all species were either flooded out of nests, or their breeding activity and behavior were inhibited by the rain during that time. With the return of normal oceanic and atmospheric conditions near Christmas Island by July 1983, the few surviving individual birds of all species began to nest again. These data extend the known sphere of influence of the ENSO on vertebrate populations and indicate that anomalous abiotic factors serve as an evolutionary forcing mechanism on tropical seabird populations.

Along the coasts of Ecuador and Peru, ENSO's are known to result in the deaths of millions of seabirds (*9*). In Peru minor ENSO's occur frequently, severe events about once per century, and major catastrophic flooding once every 600 to 800 years (*10*). Seabirds are constrained in their movements to well-defined water types (*11*), and relations between marine primary productivity and fish-squid-bird stocks in some regions are documented (*12*), but virtually nothing is known about the marine food chain of the equatorial central Pacific Ocean. However, a break in the food chain there is likely to have more subtle and complex ramifications than along coasts, since these tropical waters tend to be less productive (*13*).

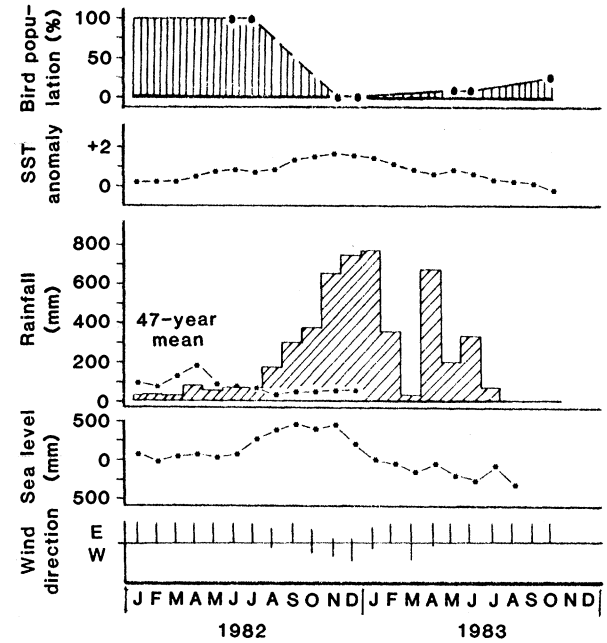

Fig. 1. Abiotic factors in the vicinity of or on Christmas Island in relation to the seabird population from 1982 to 1983 (*7*).

The ENSO in August 1982 through April 1983 in the vicinity of Christmas Island resulted apparently in major changes in primary productivity (*14*). Depleted stocks and low growth and survival rates of adult and larval fishes and squid during this period resulted in a decrease in the food supply of the birds. Decreased reproductive success and probable mortality of adult birds ensued.

In the eastern Pacific, the recovery in phytoplankton productivity after an ENSO shows the potential for a coastal upwelling system to support rapid recovery of the fish populations (*2*). But whether the equatorial pelagic system, with its inherent lower production and productivity and thus perhaps more stable interactions, can recover rapidly enough to support the seabird populations has not been shown. The opportunity now exists to compare the central Pacific depauperate nutrient system to the nutrient-rich system of the eastern Pacific. We can examine the recovery of the entire ecosystem by monitoring the return and reestablishment of the seabird breeding populations on equatorial atolls.

Our data concern seabirds that are directly affected by oceanic conditions. Other data indicate that ENSO conditions may extend to nonmarine species far from the Pacific (*15*). Field biologists must recognize that global atmospheric circulation patterns that undergo irregular anomalies may affect their study regions and species far from marine ecosystems. We suggest that ecologists examine the years 1940–1941, 1954, 1957–1958, 1963–1965, 1969, 1972–1973, 1976, and 1982–1983 (ENSO years) to determine whether heretofore unexplained anomalies occur then in their data.

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Lymphoma in Macaques: Association with Virus of Human T Lymphotrophic Family

Abstract. *Human T-cell leukemia virus has been linked with adult T-cell leukemia-lymphoma (ATLL), a tumor of mature T cells that occurs at elevated rates in southwestern Japan and in the Caribbean Basin. Human T-cell leukemia virus (HTLV) or a closely related virus, has also been found in varying proportions of healthy individuals of several species of Old World monkeys. In the present study, conducted with macaques from Taiwan and the New England Regional Primate Research Center, antibodies to membrane antigens of HTLV-infected cells (HTLV-MA) were found in 11 of 13 macaques with malignant lymphoma or lymphoproliferative disease but in only 7 of 95 of healthy macaques. This indicates that antibodies to HTLV are significantly associated with the development of naturally occurring lymphoid neoplasms in at least some species of nonhuman primates.*

Human T-cell leukemia virus (HTLV) is a type C retrovirus that was first identified by Gallo and his colleagues in a patient with cutaneous T-cell lymphoma (*1*). Numerous isolates of HTLV were subsequently made from cases of adult T-cell types of leukemia-lymphoma (ATLL) from various parts of the world (*2*). Subsequent serological surveys for antibodies to HTLV have shown a strong association between HTLV and ATLL. Natural antibodies to HTLV have been demonstrated in more than 90 percent of the patients with ATLL as well as in 4 to 37 percent of the healthy adults in areas where ATLL is endemic (*3–7*). In areas where ATLL is not endemic, less than 1 percent of the healthy adults have antibodies (*4–8*).

Evidence that an agent similar to HTLV might be present in nonhuman primates was first reported in Japanese macaques (*Macaca fuscata*) by Miyoshi and his colleagues (*9*). This observation was further extended to indicate that many Asian and African species of Old World primates have antibodies to HTLV (*10–12*). Most extensively studied were species of the genus *Macaca*. Rates of seropositivity ranging from 9 to 44 percent have been reported in healthy macaques (*10–12*). The geographic distribution of seropositive macaques in Japan does not seem to be correlated with seropositivity in human populations (*11, 12*), suggesting an independent origin for the virus in humans and macaques. To our knowledge, there has been no evidence thus far linking lymphoma or other disease with the HTLV-related agent in nonhuman primates.

A seroepidemiological survey of macaques from Taiwan and the New England Regional Primate Research Center (NERPRC), Southborough, Massachusetts, was conducted. Included were sera from three species of healthy macaques and macaques diagnosed with malignant lymphoma (ML) or lymphoproliferative disease (LPD) at the NERPRC. Serum samples examined for antibodies were obtained from 95 healthy macaques and 13 macaques with ML or LPD. Of these, 20 were from healthy adult *M. cyclopis* captured and housed in Taipei, Taiwan. All other samples were from captive macaques at the NERPRC. Included among these were: 14 healthy *M. cyclopis* and 4 with LPD; 31 healthy *M. mulatta*, 5 with ML and 1 with LPD; and 30 healthy *M. fascicularis* and 3 with ML. Both LPD and ML have been described in conjunction with macaque immunodeficiency syndrome at the NERPRC. Lymphoproliferative disease is a lesion characterized by the presence of nodular aggregates of well-differentiated lymphocytes in the liver, kidney, or bone marrow (*13*); ML is the most common spontaneous neoplasm of macaques at the NERPRC observed over the past 12 years (*14*). All the ML cases were of the non-Hodgkin's type with variability in organ distribution, cellular morphology, and grade of malignancy. The diseased monkeys in this

Table 1. Presence of antibodies to HTLV-MA in macaques from Taiwan and the NERPRC. Antibodies to HTLV-MA were detected as described (*8*). Reference HTLV-infected cell lines, Hut 102 (*1*) and MT-2 (*20*) were harvested at the peak phase of logarithmic growth. One million cells were washed twice with phosphate-buffered saline (PBS) and reacted with 40 μl of a 1:4 dilution of serum at 37°C for 30 minutes. Preparations were then washed twice with PBS and exposed to 20 μl of a 1:20 dilution of fluorescein-conjugated immunoglobulin G fraction of goat antiserum to monkey immunoglobulin G (Cappel, Cochranville, Pennsylvania). The samples were incubated at 37°C for 30 minutes, washed twice with PBS, and examined for fluorescence. Samples were considered positive when more than 40 percent of the target cells showed fluorescence. Positive and negative human reference sera were included in each test. Sera that initially scored positive were tested on two uninfected human lymphoid cell lines, 8402, a T-cell line (*21*), and NC 37, a B-cell line which lacks surface immunoglobulin in (*22*), to confirm specificity.

Species	Clinical status	Origin	Number tested	Number positive	Percent positive
M. cyclopis	Healthy	Taiwan	20	2	10.0
	Healthy	NERPRC	14	2	14.3
	LPD	NERPRC	4	3	75.0
M. mulatta	Healthy	NERPRC	31	1	3.2
	LPD	NERPRC	1	1	100.0
	ML	NERPRC	5	4	80.0
M. fascicularis	Healthy	NERPRC	30	2	6.7
	ML	NERPRC	3	3	100.0
Total*	Healthy		95	7	7.4
	ML/LPD		13	11	84.6

*Difference between healthy and ML or LPD significant at $P < 6 \times 10^{-9}$ with Fisher's exact test.