The 1982–
some of its consequences

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The warm event, El Niño, that struck the eastern equatorial Pacific in 1982–83 was the strongest recorded in the last 100 years. Coastal people suffered floods, crop losses and failure of fish catches as the ocean waters grew warmer and the rainfall increased more than tenfold. Wildlife was affected in many different ways. The author has been working as a Naturalist Guide within the Galápagos National Park for the past three and a half years and he is particularly interested in the interactions of seabirds with their environment.

At irregular and unpredictable intervals exceptionally warm surface waters appear in the central and eastern tropical Pacific Ocean, disrupting climate and ocean conditions. The occurrence is referred to as El Niño* and it usually begins in December, around Christmas time (El Niño is Spanish for Christ-child).

In order to place El Niño in context, it is worth outlining the usual seasonal pattern in the eastern equatorial Pacific. In the cool season, when many Galápagos animals breed, the south-east trade winds blow. These winds are a vital climatological facet in the productivity of the eastern Pacific, drawing surface water off the coast of South America and allowing cold nutrient-rich water to the surface to recycle its wealth. On these nutrients depend the organisms which are food for millions of birds, mainly boobies, cormorants and pelicans, and which are also the base for the extraordinarily productive anchovy fishery on the west coast. The winds also drive huge sections of the surface waters of the Pacific Ocean westwards, causing a rise in sea-level in the western Pacific. Part of the return system is via the North Equatorial Countercurrent, which passes well to the north of the Galápagos archipelago. Another section returns as the cold (15.5°C at 100 m depth) Cromwell Under-Current. Its core may be 200 m thick and 400 km wide and somewhere between 20 and 250 m below the surface and within 50 km of the equator. It is this current that causes unstable water mixing within the Galápagos and is of great importance in preserving the extraordinary diversity of animals, some of which are of subantarctic origin. The sea surface temperatures may fall as low as 16°C. In December there is a change to a warmer climate as the Intertropical Convergence Zone (area of convergence of the north-east and south-east tradewinds) moves southwards and the sea temperature increases.

Since 1940 there have been 10 'warm events' or Niños. The most obvious feature of one of these exceptional years is a rise in sea surface temperatures. The question is, where does this come from? In 1982–83 there were believed to be two sources: (1) warm water in large quantities from

*According to the definition of the Scientific Committee on Oceanic Research (Working Group 55), El Niño occurs when the monthly mean departures of sea surface temperatures from the 25-year long-term monthly mean value exceed 1 standard deviation for four consecutive months at three of five coastal stations of Peru (Talara, Puerto Chicama, Chimbote, Isla Don Martin and Callao). At the end of 1982 surface temperatures exceeded the long-term means by 5 or more standard deviations at most of these stations (Halpern *et al.*, 1983).

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the northern Panama area, and (2) an unprecedented supply of warm water travelling from the western to the eastern Pacific. Some believe this first source to be the principal cause of most Niño years, with hot water appearing off the west coast of South America and moving westwards until it may affect the whole equatorial region. The second source is apparently more rarely associated with the Niño years, although studies are in their infancy. There is a suggestion that the 1982–83 Niño was in fact two events, the first triggered in the western Pacific, which peaked in the east in December–January and perhaps masked the arrival of the hot conditions from the north, which persisted as high sea surface temperatures (4–8°C higher than normal) until June–July in the Galápagos, and which might have been a Niño in its own right.

Although little is yet known about the ultimate cause, or causes, of El Niños, it seems that the abnormal conditions may be associated with changes in the normal relationships between pressure areas in the Pacific: the pressure gradient is virtually reversed, allowing equatorial westerlies to blow (i.e. from the west, whereas the normal wind flow is towards the west). The gradient in 1982 was greater than had been ever recorded since records began 35 years previously and the resultant winds were strong. Because of the imbalance already set up in sea-level heights across the Pacific, these winds triggered sub-surface wave patterns to surge across this ocean, carrying warm water with them, raising the sea-level within the Galápagos archipelago by 22 cm and causing extensive flooding in Ecuador. It also allowed troughs to form in both hemispheres and the formation of tropical cyclonic storms, some reaching hurricane force, which in unprecedented strength and number hammered their way through French Polynesia. The westerlies, which began in July 1982, had by December 1982–January 1983 reversed the current flow of the equatorial surface waters and from mid-January to mid-February the cold Cromwell Under-Current disappeared to at least 250 m depth at 109°W. The temperature at 100 m was 27.5°C, 1°C cooler than the surface. This is 12–13°C warmer than in inter-Niño years. This huge volume of very warm water inundated the tropics of the eastern Pacific as far as the west coast of the Americas and set the scene for ecological drama.

Warm water invasion

Having summarised the background environmental changes that occurred during the period July 1982 to December 1983, I would like to make specific reference to the main Niño area, the coastal areas of South America within the tropics, and the Galápagos Islands in particular. The unparalleled invasion of warm water into the region had two major outcomes. First, a very high rate of evaporation developed and strong convection currents wafted the wet air to high altitudes, producing magnificent cumulus and cumulo-nimbus cloud formations, which resulted in storms of exceptional intensity. Between October 1982 and July 1983, 3264 mm of rain were recorded at the Charles Darwin Research Station; an average figure is 254 mm a year and the area is classified as a botanical desert. Secondly, the upper 100 m of the sea became very stable. The blue, clear warm water may have been aesthetically pleasing but, nutritionally, it was a frighteningly empty place. The productivity

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of the sea is extremely complicated, but the one most important factor is the recycling of essential elements to the surface, or at least to the zone that is reached by sunlight. I do not believe that anyone envisaged how rapidly this altered environment would be reflected in the web of life.

Tortoise exodus

If we consider two zones in the Galápagos, the arid, low-altitude areas characterised by scrub and cactus forest, and the rich intertidal and submarine environment, we find the effects of the two major features of El Niño are to reduce species diversity and abundance. The super-abundance of rain causes considerable damage to crops, removes topsoil, sends torrents of water surging and cascading down the ravines to the coast. According to Alf Kastdalen, a Norwegian who arrived in the islands in 1935 and has been a keen observer of Galápagos since, these ravines were filled 14 times in 1940–41, when there was another exceptional El Niño which also began out of season. In 1982–83 the ravines flowed more than 30 times. But Kastdalen also pointed out that since the 1940s man has damaged the ground in the farming areas by fires, by removal of the spongy moss-liverwort cover and protective shrubs, and by the development of a hard pan by ever-increasing cattle movement; thus these factors could account for the increased run-off, at least in part.

Flood waters coursed through the Tortoise Reserve on Santa Cruz and so unnerved the giant tortoises that they abandoned their highland homes for the drier coastal lands. Linda Cayot, studying tortoise–plant relationships, gave up her study as an initial migration turned into a rout, and no tortoises were seen in the highlands for several months. Although in the past it has been difficult to imagine inter-island colonisation by these enormous beasts, it is not now difficult to visualise them being swept into the ocean by the violence of the floodwaters. Where the waters flowed they left a swath of destruction, with *Opuntia* cacti snapped like twigs in a gale.

The effect of the rain varied with species. Some plant families, especially the Convolvulaceae, responded with extraordinarily luxuriant growth. *Ipomoea* sp. and *Merremia aegyptica* on the coast, and *Stictocardia tiliifolia* in the highlands, climbed up and over rock, bush and small tree, submerging all in undulations of verdure, as if green snow had fallen. The appearance of ponds all over the islands offered great opportunities to insects. Hood Island became untenable by human beings because of the massive explosion of mosquitoes (*Aedes* sp.) and perhaps by the blue-faced boobies *Sula dactylatra*, whose chicks had bare necks from irritation by these parasites. And on the land, insect larvae, which stripped bushes of their leaves, provided abundant food for terrestrial birds whose populations are usually limited by the lack of protein foods for the young. The amazing comparison between the breeding seasons of the Darwin's finches in the years 1982 and 1983 on the small island of Daphne Major will serve as an example. In 1982 60 nests were started at the beginning of the rainy season; all were abandoned for lack of food. But from December 1982 to the following June 1000 young birds were ringed. Some pairs bred four or five times and some birds hatched early in the season were themselves breeding by June. The genetic variation which must now be available is staggering. Soon selection pressure will bear down more heavily as more stringent times approach, but the future of the species must be optimised by these explosions in numbers.

Disaster for seabirds

I would like to remark here, albeit unscientifically, that the impression one had in 1983 was of organisms caught in the circumstances of the times and as victims of fate rather than as finely-adapted results of evolution. The solid, water-storing trunks of the tall *Opuntia* cacti may adapt the plants to outcompete other species in normal conditions but that endowment did not stop the engulfing vines, nor did it prevent them being felled by their own weight as the pads became engorged with life-giving, or death-bringing, moisture.

The coastlands are the main reproductive area for the seabirds and here disaster struck, an outcome not restricted to Galápagos. From Christmas Island (157°W, 2°N), which has huge populations of terns—the colony of sooty terns *Sterna fuscata* alone is estimated at 14 million—shearwaters, frigatebirds, red-footed and blue-faced boobies, Ralph and Anne Schreiber (1983) reported: 'During our visit in November 1982 we discovered virtually a total reproductive failure on the island; the bird populations had essentially disappeared, and many dead and starving nestlings were present.' Although Galápagos cannot boast of such enormous colonies, the effect on its seabirds was similar. Heavy rains swamped the nesting areas of the boobies, ruining many eggs, and pathetically sodden birds were trying to ease the eggs out of puddles with their bills.

The waved albatros *Diomedea irrorata* of Galápagos had a very poor year in 1982, with about 60 per cent egg desertion, most probably from lack of food, and 1983 was even worse. Cathy Rechten abandoned her studies of this species after she ended up watching, within her whole study area, one incubating adult, and that not even incubating its own egg. Not only were eggs destroyed by rain, but many fell through the dense ground cover which had grown up, and were lost. By the end of December 1982 there was a stark contrast between the lush vegetation and the desperately begging young albatrosses finding no succour from their parents, which had spent days scouring the blue, vacant water. Despite the disastrous season, they returned at the end of March 1983 to try again, even though the productivity of the seas had not improved.

The shortage of food became acute and affected all animals that have a relationship with the sea. There was a remarkable correlation between increasing sea surface temperatures, rainfall anomaly and sardine catch (Chavez *et al.*, 1983). By December 1982 the catch was falling; in February–March 1983 it checked itself momentarily as the temperature fell slightly; in April 1983 it plummeted to zero as temperatures soared to 25°C—a 10°C anomaly.

Soon, those animals that could flee did so. Blue-footed boobies *Sula nebouxii* vanished from their colonies and were not seen in any numbers on their breeding grounds until June–July 1983. Although the blue-faced boobies *S. dactylatra* persisted in trying to raise their young well into 1983, by the time the blue-foots were returning the blue-faced boobies had vanished. The beautiful endemic swallow-tailed gulls *Creagrus furcatus* also disappeared early in the year and only started to return in June. Even now, in December 1983, I have only seen one bird with an egg, although much courtship is in evidence. One missed their buoyant flight of white over black basaltic rocks.

Frigatebird failure

The great frigatebirds *Fregata minor* had a spectacular display season in April–May 1983 and then apparently completely abandoned all attempts to breed. The salt bush *Cryptocarpus pyriformis* plants on top of which they breed, would be growing lank by now if it were not for the fact that the red-footed boobies *S. sula* have moved in, taking advantage of the absence of the frigatebirds, and are keeping them cut back by removing twigs for nesting material. The red-foots have bred continuously during this difficult time, although at a lower rate, for they are adapted to feeding far from land in impoverished water on prey species such as flying fish and squid.

The failure of the great frigatebird is interesting because they are apparently catholic feeders as far as fish species are concerned. This either means that a large number of shore species disappeared or went deeper in the water, or that frigatebirds are much more dependent on stealing other birds' food than I had realised: with boobies not returning to their colonies, food of this kind was indeed scarce. The traditionally fished grouper, bacalao *Mycteroperca olfax,* was not caught for many months. In its place we had a prodigious influx of yellow-finned tuna *Thunnus albacorus,* dorado *Coryphaena hippurus* and wahoo *Acanthocybium solandri,* all blue-water predatory species. Sharks and turtles fled south, as did many birds, probably following the boundary of water masses where some mixing was still occurring.

Plight of the flightless

Some could not flee. Surveys of Galápagos penguins *Spheniscus mendiculus* and Galápagos flightless cormorants *Nannopterum harrisi* revealed that the numbers of penguins fell from 1720 in 1980 to 398 in 1983, and that numbers of flightless cormorants were reduced to 409 from

802 in the same period (Valle, in press). It will require another survey in 1984 to verify the damage done to the populations, as these figures may reflect a very wide scattering of members of the species and could account for the setting up of new colonies of flightless cormorants, normally an extremely sedentary species.

Seaweeds and corals died everywhere. On average about 90–95 per cent of hermatypic corals (reef-forming corals—which are characterised by the presence of symbiotic unicellular algae in their tissues) died. This was true of genera such as *Pavona, Porites* and *Pocillopora,* and soon the naked white domes were covered with a monotonous filamentous alga. However, I was fascinated to see that the unattached fungus corals, which, when I last saw them in June 1983, were looking extremely vulnerable, alive but transparent, revealing every detail of their fine calcareous skeletons, had in fact survived and by November 1983 were once again clothed in green and brown.

Iguanas starved

The marine iguanas *Amblyrhynchus cristatus* have shown themselves to be very vulnerable and poorly adapted to these changed times. They seem to depend upon certain species of algae and are unable to deal with many others because of the limited ability of their stomach microbes to break down the cellulose of cell walls (Andrew Laurie, pers. comm.). With the death of whole carpets of algae such as *Ulva* spp., the iguanas were doomed. Thousands died. Their skeletons now lie under nesting cormorants.

The fur seals *Arctocephalus galapagoensis* and *A. australis* in Peru both fared very badly. These animals are shallow divers (20 m or so) and feed mostly at night, perhaps largely on octopuses and cuttlefish, and the rise in water temperature may have inhibited the vertical migrations of these animals or may have caused them to migrate laterally. In any case, by mid-February all but one pup of 90 originals were dead from starvation at Cape Hammond on Fernandina Island. It was a pathetic sight to see the hard outlines of vertebrae and ribs as food became more and more scarce. Pup mortality, from limited observation, was 40 per cent in 22 days for *A. australis* at Punta San Juan in Peru, where water temperature anomalies were similar to Galápagos (+9°C). In 1979 pup mortality was estimated to be 10 per cent during the first month of life.

The turn of the wheel

The event ended abruptly, in July 1983. Rainfall figures at the Darwin Station for July were 278.2 mm and for August 5.2 mm. This coincided with a strong increase in the south-east trade winds and a 2–3°C drop in sea surface temperatures. Up to December 1983 there was no sign of a re-entry of warm water.

Although all life was affected, with some species experiencing a population explosion and others a dramatic decline, none was, as far as we know, eliminated by these changes and perhaps many survive as they are because of these periodic 'tests of strength'. It is difficult now (December 1983) to appreciate the extent of the events that occurred; the islands seem so normal. The swallow-tailed gulls, sharks and turtles are back; boobies are displaying in their old haunts; marine iguanas lie fat beside new green algal beds; the grouper are back and fishing is good; flamingos and flightless cormorants are raising their young; penguins are moulting, a sign of possible breeding. And the old giant tortoises, which may have lived through several such seasons, have ambled back to their highland ranges, using the stream beds cleaned by the thundering waters. The wheel has turned.

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The author is selling prints of his paintings of Galápagos penguins, flightless cormorants and great frigatebirds to raise funds for conservation in the Galápagos.