GLOBAL WARMING AND THE GALAPAGOS

By: Peter R. Grant and B. Rosemary Grant

The idea that organisms evolve was transformed during the last century from conjecture to fact. As the present century draws to a close, we are experiencing another transformation. The conjecture that the world's temperature is gradually rising has become widely accepted as a demonstrated fact. A warming trend took place from 1880 to 1940. There followed a slight reversal, but from 1975 onwards the warming has resumed, and the 1980s were undoubtedly the warmest decade of the century (Fig. 1).

There has been much discussion about the exact role of human activity in producing this effect, through, for example, the large-scale cultivation of rice and domestication of cattle and sheep, combustion of fossil fuels, destruction of forests, the alteration of gases in the atmosphere such as carbon dioxide and methane, and by all this the creation of a greenhouse effect. It is still too early to be sure if the human influence is substantial and increasing, in which case global warming will continue well into the next century; or if it is minimal, in which case the trend may once again be reversed. Effects of global warming are likely to be more severe in parts of the temperate zone than in tropical Galápagos. Nevertheless, we should be thinking about the implications of global warming for Galápagos.

We should not wait until we can be sure that Galápagos is affected. Change is already underway. A global rise in sea level over the last 100 years from the melting of polar ice has been estimated at 10-30 cm. A measured 6% decrease in the extent of arctic ice occurred over the comparatively short time of 15 years, from

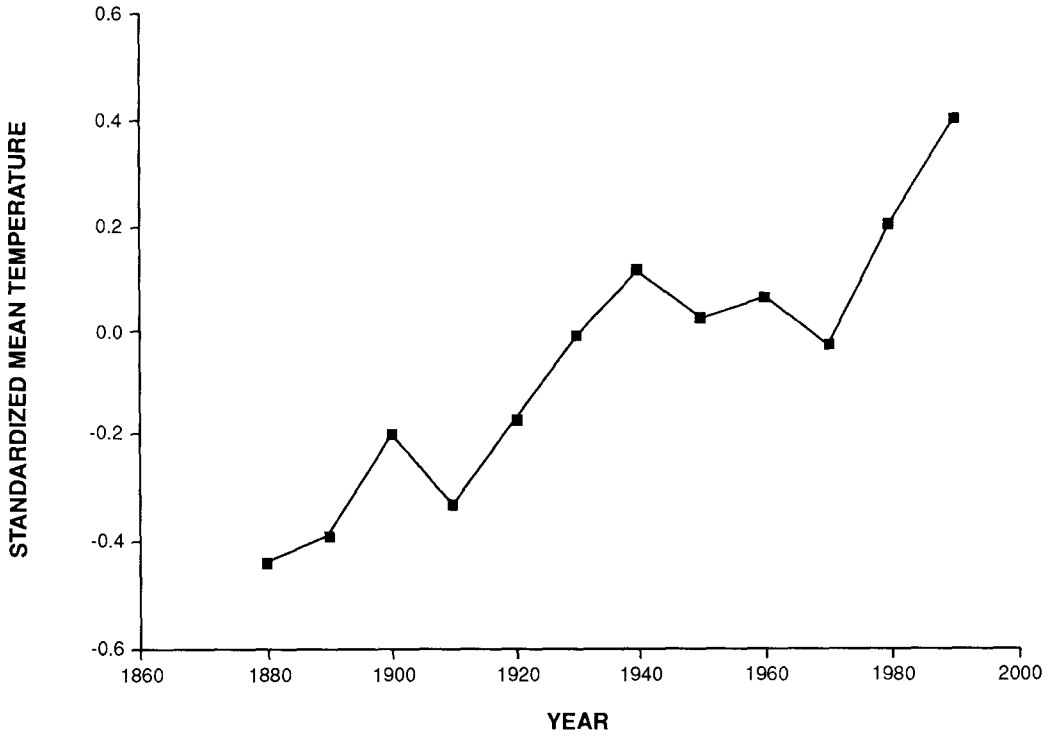

Figure 1. Global warming over the last 100 years. Adapted from the National Science Foundation (USA) publication *Mosaic* (1989, volume 20, number 4).

1973 to 1988. Projecting these trends into the future is hazardous of course, but by one calculation a global warming of 4°C to 5°C will occur by the year 2050, and much more arctic ice will have melted as a result. As reported in the April 1991 issue of *Ecology* (72:373-412), predicted temperatures for the next century will be higher than any experienced by the earth's biota during the last several million years, and the projected rates of change may be more than an order of magnitude faster than any global change in the past 2 million years!

The extraordinary El Niño event of 1982-83 (Robinson and del Pino 1985, Glynn 1988) gives us some basis for estimating the effects of a general warming on life in Galápagos. Glynn (1990) has speculated that effects of El Niño might mimic on a very short time scale what could happen over a much longer time period through global warming. Given the widespread decimation of corals during 1982-83, Glynn suggested that they are in danger of being eliminated. If sea temperatures increase markedly over a century, it is doubtful if natural selection could act fast enough to be effective in molding an adaptive response in long-lived species like these to stressful thermal conditions. A rise in the sea level as a result of polar ice melting, decreased salinity, and increased turbidity could exacerbate the stress. The combination of all these factors and other physicochemical changes would kill corals and cause extinctions, as happened off the Pacific coast of Panamá during the 1982-83 El Niño event (Glynn and de Weerdt 1991). The proportions and numbers of organisms associated with them, like damselfish and sea urchins, would change, perhaps drastically, as a consequence.

A possible key to predicting the future lies at the interface of the ocean and the atmosphere, for it is here that interactions determine the occurrence of El Niño-Southern Oscillation events, their severity, duration, and frequency (Philander 1990). The atmosphere is more thermally labile than the oceans, hence the climate will undergo change more rapidly than will the sea.

The most likely effect of global warming on Galápagos is higher average temperatures, with perhaps greater contrasts between the warm and wet El Niño years and the cool and dry intervening years. After the 1982-83 El Niño event, several populations of animals, land-based entirely or in part, suffered crashes. These included various species of sea birds (Rosenberg et al. 1990), land and marine iguanas (Laurie 1990), and sea lions and fur seals (Limberger 1990). Most recovered fairly quickly, possibly more quickly than much of the vegetation (Grant and Grant 1990). Their recovery was helped by the more moderate effects of the next event in 1987. Nevertheless, it is not difficult to envisage major and long-lasting effects of severe events like the 1982-83 one if they were repeated every 4 years. Populations of plants and animals will have altered distributions in the Galápagos. Some will be driven extinct by a combination of direct and indirect effects: by the direct effects of high temperatures, high rainfall, and high annual variation in both, and the unpredictable indirect effects arising from predators, parasites, competitors, and various interactions in the community food web.

The prediction of high temperatures and rainfall is not certain however. This is underlined by the fact that global greenhouse warming could intensify alongshore windstress on the eastern Pacific Ocean surface, leading to greater coastal upwelling (Bakun 1990). This, in turn, would cause a cooling of the ocean surface and an amelioration of dailing heating of the ocean offshore, with the possible result of reduced convective cooling and precipitation on Galápagos. However, alongshore windstress has been increasing during the last 40 years, and so have trade winds (Bakun 1990), without a noticeable drop in precipitation recently.

In the issue of *Ecology* referred to above, a committee of the Ecological Society of America confronted the task of planning globally for an uncertain future. Several key points were made about the possible effects of global warming that are as relevant to Galápagos as elsewhere. For example, it was pointed out that a challenge for ecologists is to understand processes which link species and ecosystems with climate and to predict ecological responses under *climates that do not presently exist*. Evolutionary responses are important too (Grant 1991). It is known that natural selection favoring tolerance to heat or dessication can lead to the rapid evolution of general stress-tolerant genotypes which are resistant to a variety of environmental stressors and which have

altered life history characteristics like growth and reproductive rates.

Planning for an uncertain climatic future in the Galápagos should start now. The few long-term studies currently being conducted need to be multiplied to provide the necessary baseline data for assessing the effects of a gradually altered environment. Attention should be given to the design of environmental and biotic monitoring and the analyses of data that will serve the needs of the 2040s as well as the 1990s. A conference of experts would be helpful.

The *Ecology* article concluded by raising many research questions which cannot be answered (fully) at present, and which should guide future research activity. These include:

1) How does climate change affect plant and animal dispersal and colonizing ability?

2) What are the key species whose presence or absence can critically alter the composition of local communities?

3) How does genetic structure affect the long-term evolutionary responses of populations that are becoming rare and in danger of extinction?

4) How are demographic parameters of species and interspecific interactions affected by evolutionary changes in physiological tolerance?

5) How rapidly does the likelihood of extinction increase with a change in climate? How rapidly can species respond evolutionarily to a change in climate?

Studies on Galápagos can contribute more than most studies to answering these and a host of related questions because long-term studies have already been conducted for many years as has environmental monitoring. More importantly, several Galápagos communities are in a natural state, having been unaffected by human activity; and the interpretation of any changes that are documented should be unambiguous, providing that those communities are preserved in their natural, unmanipulated, state.

Climate change should be anticipated, measured, and understood, as it clearly impinges on long-term plans for biological conservation in Galápagos.

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