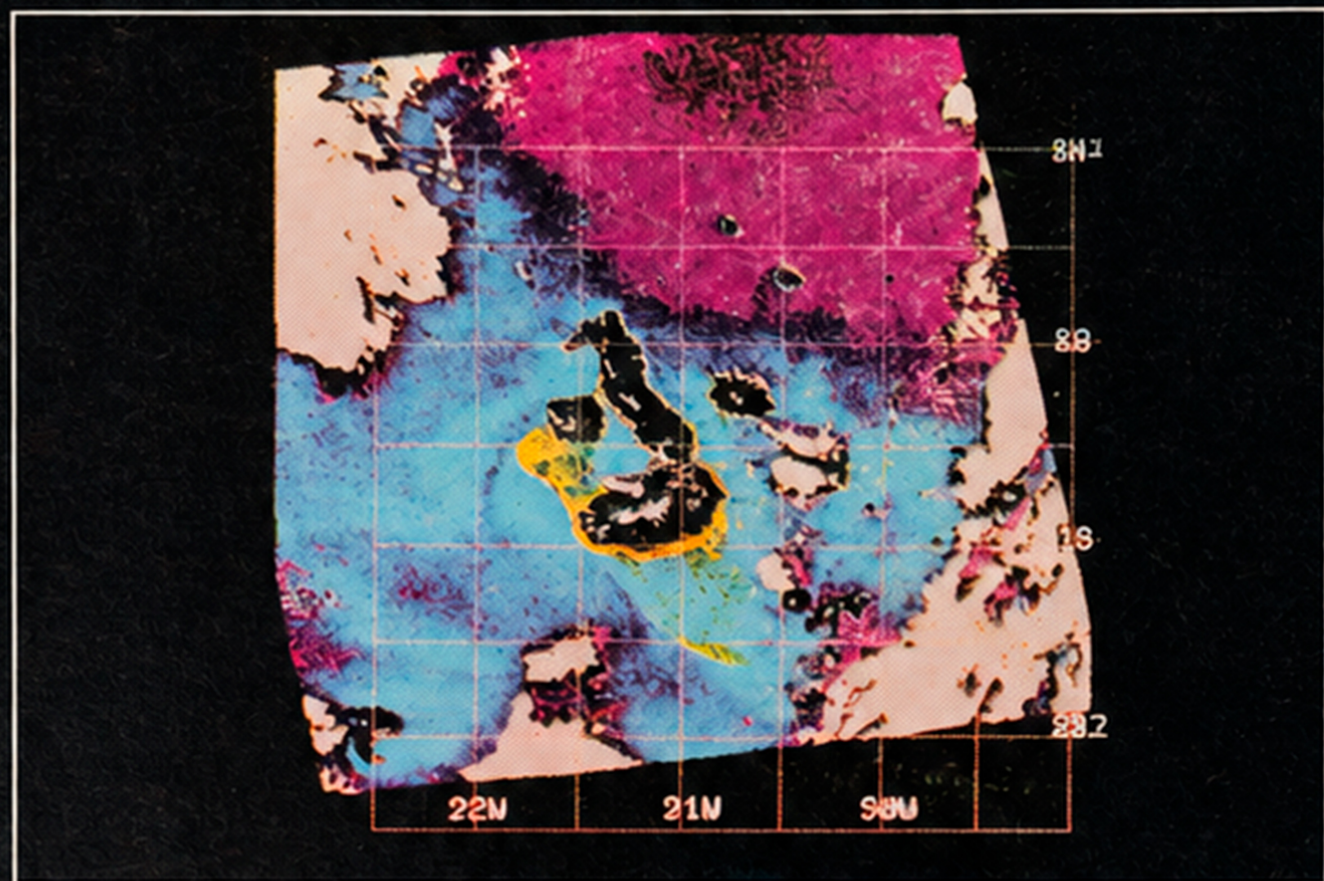


EL NIÑO EN LAS ISLAS GALAPAGOS

EL EVENTO DE 1982 – 1983



EL NIÑO IN THE GALAPAGOS ISLANDS: THE 1982 – 1983 EVENT

Gary Robinson
Eugenia M. del Pino

Publicación de la Fundación Charles Darwin para las Islas Galapagos, Quito, Ecuador, 1985.

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El Niño en las Islas Galápagos: El Evento de 1982 — 1983 es un compendio de artículos escritos por especialistas y por habitantes de las Islas Galápagos. Los eventos El Niño ocurren cada año, pero nunca antes se registraron con tanta intensidad. La Fundación Charles Darwin para las Islas Galápagos apoyó la colección y publicación de estos artículos e invita a los científicos y planificadores a hacer uso de esta historia en la enseñanza de una lección básica en conservación.

El libro está dividido en cinco partes. La primera describe los cambios oceanográficos y meteorológicos y da de esta manera un marco de referencia para las secciones siguientes. La segunda parte es una descripción general de las alteraciones observadas y sirve a modo de introducción a las otras secciones más específicas sobre los cambios en la vida marina y que depende del mar, la vida terrestre y los efectos sobre el hombre y sus actividades.



Asistente del
Director.

**EL NIÑO EN LAS ISLAS
GALAPAGOS:
EL EVENTO DE 1982-1983**

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GALAPAGOS ISLANDS:
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Galápagos Islands, Quito, Ecuador, 1985.

Portada: Imagen derivada de satélite de la distribución de pigmentos fitoplanctónicos a comienzos de El Niño 1982-83 (8 de noviembre de 1982). La gran región de color púrpura en la parte superior corresponde a una zona muy pobre en la concentración de pigmentos (0.1 mg por metro cúbico). Su posición corresponde a la del Frente Ecuatorial para esta época del año.

Contraportada: La imagen derivada de satélite del 11 de junio de 1981 muestra una distribución típica de fitoplancton. El área de color anaranjado-rojizo corresponde a concentraciones de pigmento de 1.5-3.0 mg por metro cúbico. La presencia de esta región altamente productiva caracteriza a las aguas que rodean el Oeste de Isabela y a Fernandina. En comparación, durante El Niño 1982-83, (ver la portada) las aguas interiores de Galápagos tenían una concentración reducida de pigmentos. (Cortesía de Gene Feldman, State University of New York at Stony Brook)

Cover: Satellite derived image of phytoplankton pigment distribution in the Galápagos Islands at the onset of the 1982-83 El Niño, 8 November 1982. The large purple region at the top corresponds to a region of extremely low pigment concentration. (0.1 mg per square m). Its position is approximate to the location of the Equatorial Front reported for this time of year.

Backcover: The satellite-derived image from 11 June 1981 displays a typical distribution of phytoplankton. The orange to red area corresponds to pigment concentrations of 1.5-3.0 mg per square meter. The presence of this highly productive region is characteristic of the waters around western Isabela and Fernandina. In contrast, during El Niño 1982-83 (see cover), the interior waters of the Galápagos had a reduced pigment concentration. (Courtesy of Gene Feldman, State University of New York at Stony Brook)

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GALAPAGOS:
EL EVENTO DE 1982-1983**

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GALAPAGOS ISLANDS:
THE 1982-1983 EVENT**

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INTRODUCTION

The Charles Darwin Foundation for the Galapagos Islands asked us to collect and edit information about the changes that occurred in the Galapagos Islands as a result of El Niño 1982-83. We began to work on this project in September 1983. Immediately we contacted possible authors and they gave us a prompt and positive answer. The edition of this volume took time and now, two years later, the book is complete.

The articles describe the characteristics of El Niño in the Galápagos Islands and changes that it brought about in the archipelago. Articles are written by specialists and by local inhabitants of the islands. We divided the contributions in five sections. The first one describes oceanographic and meteorological changes in the Islands. It gives a reference framework for the sections that deal with specific changes on marine and terrestrial life. We named the second section El Niño in Galápagos. This part contains only one article, written by G. Merlen. He describes the changes observed in the archipelago during this period and his personal impressions. The article serves as an introduction to the more specific sections on changes that occurred in marine life and that of sea dependent organisms, terrestrial life, and the effects on man and his activities.

The book contains articles written in Spanish and articles written in English. Authors used the language in which they felt more comfortable. To facilitate understanding, each article contains summaries in both languages.

INTRODUCCION

La Fundación Charles Darwin para las Islas Galápagos nos encargó la tarea de recolectar la información sobre los trastornos ocurridos en las Islas Galápagos a consecuencia del fenómeno El Niño de 1982-83 y de editarla en forma de un libro. Iniciamos el trabajo en septiembre de 1983, y nos pusimos enseguida en contacto con los posibles autores de los artículos. La respuesta fue positiva e inmediata, sin embargo la edición del volumen tomó tiempo. Ahora dos años después, el libro está finalmente listo.

El fenómeno El Niño 1982-83 en Galápagos y los trastornos que produjo están descritos por los especialistas y por los habitantes de las islas, quienes vivieron las alteraciones del ambiente. Hemos dividido al libro en cinco partes. La primera describe los cambios oceanográficos y meteorológicos y da de esta manera un marco de referencia para las secciones sobre los efectos en la vida marina y terrestre. La segunda parte del libro, intitulada: El Niño en Galápagos, contiene solamente el artículo de G. Merlen, quien relata los cambios que observó en el Archipiélago durante ese período y su reacción personal ante el fenómeno. Este artículo sirve a modo de introducción a las secciones más específicas sobre los cambios en la vida marina y que depende del mar, la vida terrestre y los efectos sobre el hombre y sus actividades.

El libro junta artículos escritos tanto en Español como en Inglés; pues los autores usaron aquel idioma en el podían expresarse mejor. Para facilitar la comprensión se han incluido resúmenes en ambos idiomas para cada artículo.

XVI Introduction

We acknowledge the cooperation received from authors. With their articles, they collaborated in this effort to document changes that occurred in the Galapagos Islands as a result of El Niño 1982-83. We acknowledge also the help of other persons who have given us support in this effort. For us, the edition of this book was an unusually interesting experience. We hope that users of this volume will find it also interesting. We hope that the information contained here will give basis for comparison in future studies.

Gary Robinson

Eugenia M. del Pino

September, 1985

Introducción XVII

Agradecemos a los autores de los artículos, quienes con sus trabajos han colaborado en este esfuerzo por documentar los cambios que se operaron en las Islas Galápagos por efecto de El Niño en 1982-83. Agradecemos igualmente a todas las otras personas que han apoyado en este trabajo. La edición del libro ha sido para nosotros una experiencia sumamente interesante. Esperamos que este volumen sea igualmente de interés para los lectores y que provea de una base de comparación en estudios futuros.

Gary Robinson

Eugenia M. del Pino

Septiembre de 1985

FOREWARD

An observer visiting the Galápagos for the first time during the early part of 1983 would have found a situation very different from the impression he may have received from books and films. The normally arid archipelago, which is home to so many drought-resistant plant and animal species, would have been swept with rain. The seas, otherwise relatively cool and rich in nutrients, would have been abnormally warm and unproductive.

Sweating inside his raincoat, the novice visitor would have stumbled through puddles, lakes, and streams, wondering why they were devoid of frogs and fresh water fish. As he trudged along saturated coastlines, he would have witnessed the starvation of seals and marine iguanas, which usually feast on the rich life in the surrounding ocean.

All these dramatic phenomena told the inhabitants and experienced observers in early 1983 that something exceptional was happening: El Niño events occur every year, but never did anyone record such deluvial rains and bath-tub ocean temperatures.

A record of these events and of their effects on the Galápagos is of great interest. The Charles Darwin Foundation for the Galápagos Isles, an international organization established in 1959 to investigate the archipelago and to preserve its ecosystems, therefore attached great importance to collecting and publishing the accounts of those exceptional and exciting months.

PREFACIO

Un observador que hubiera visitado las Galápagos por primera vez a comienzos de 1983 habría encontrado una situación muy diferente de la impresión que tendría de libros y películas. El archipiélago normalmente árido, hogar de tantas especies de plantas y animales resistentes a la sequía, habría aparecido como lavado con lluvia. Los mares, que son relativamente frescos y ricos en nutrientes, habrían estado anormalmente calientes e improductivos.

Sudando dentro de su impermeable, el visitante novato se habría tropezado con charcos, lagos y corrientes, preguntándose por qué estaban libres de ranas y de peces de agua dulce. Conforme caminara con fatiga a lo largo de las líneas costeras saturadas, sería testigo de la inanición de focas y de iguanas marinas, las que usualmente se banquetean en la rica vida del océano circundante.

Todos estos fenómenos dramáticos informaron tanto a los habitantes como a los observadores expertos a comienzos de 1983 que algo excepcional estaba sucediendo: Los eventos El Niño ocurren cada año, pero nunca se registraron semejantes lluvias diluvianas y temperaturas en el océano comparables a las de una bañera.

Un registro de estos eventos y de sus efectos en las Islas Galápagos es de gran interés. La Fundación Charles Darwin para las Islas Galápagos, una organización internacional establecida en 1959 para investigar el archipiélago y para preservar sus ecosistemas, dio gran importancia a la colección y publicación de las narraciones de habitantes y visitantes que documentan los eventos durante aquellos meses excepcionales.

We believe that evolutionary scientists, ecologists, and environmental planners alike may profit from the publication of these chronicles. The Darwin Foundation calls upon scientists and planners to make use of this case history when teaching a basic conservation lesson. Populations and biotic communities must be sufficiently protected and large enough to be safe not only when average environmental conditions prevail, but also during times of climatic extremes and stress.

The Darwin Foundation supports the Ecuadorian Government in its effort to protect the natural heritage of the Galápagos Islands, so that their unique variety of fauna and flora might be preserved for the generations of future millennia.

Peter Kramer
President
Charles Darwin Foundation

Creemos que los científicos evolutivos, ecólogos y planificadores ambientales, por igual, pueden beneficiarse de la publicación de estas crónicas. La Fundación Charles Darwin invita a los científicos y planificadores a hacer uso de esta historia en la enseñanza de una lección básica en conservación. Las poblaciones y comunidades bióticas deben estar protegidas y deben ser suficientemente grandes para estar seguras no sólo cuando prevalecen las condiciones ambientales habituales, sino también durante tiempos con condiciones climáticas extremas y con tensión.

La Fundación Darwin apoya al Gobierno Ecuatoriano en sus esfuerzos por proteger la herencia natural de las Islas Galápagos, de modo que su singular variedad de fauna y flora pueda ser preservada para las generaciones de milenios futuros.

Peter Kramer
Presidente
Fundación Charles Darwin

EN MEMORIA DE ALF KASTDALEN
(1925-1983)

Alto, robusto, tremendamente fuerte, trabajador, afable, buen conversador, versado en varios temas, gran conocedor de la naturaleza humana, así fue Alf Kastdalen. Ciudadano del mundo, como él mismo escribe, creía en un futuro mejor cuando se subestimen las fronteras nacionales y se dé valor al planeta. Era creyente de las leyes de la naturaleza impuestas por Dios y en la salvación del hombre mediante el descubrimiento y obediencia a las leyes naturales; amante de la verdad, de la vida como una misión; Autoeducado en base a buena lectura constante, estaba convencido de que la mejor forma de ayudar a los demás era enseñándoles a ayudarse a sí mismos; pagaba bien a sus empleados y acogía siempre a quienes llegaban a su casa. Según su esposa, Alf era cariñoso con su familia y respetuoso con sus padres.

Nació en el poblado de Rjukan (Noruega) el 12 de agosto de 1925 y vino a Santa Cruz, Galápagos, con sus padres Torbal y Martha María en 1935. La gran depresión mundial de los años 30, la inminencia de una segunda guerra mundial y la escasez de trabajo en Noruega obligaron a la familia a tomar la decisión de viajar a las remotas islas ecuatorianas.

A pesar de las contradictorias informaciones que tenían sobre la naturaleza insular, que incluían la de ser un paraíso fantásticamente fértil donde se cosechaba todo lo que se sembraba (un informante aseguraba haber plantado con sus propias manos suficientes naranjos como para satisfacer de naranjas a media Noruega); que el clima era el mejor del

mundo: llovía al iniciar la noche y escampaba a la salida del sol; que aún en el peor estiaje había la posibilidad de coleccionar suficiente agua dulce para las necesidades diarias. Por otro lado, supieron que había fracasado una expedición noruega, que las partes bajas de las islas eran secas y que no había fuentes ni ríos; que habrían de instalarse en la parte alta de la isla escogida, a 9 kilómetros de la playa, y que no existían caminos, comunicaciones, médicos ni medicinas, y que vivirían en condiciones muy primitivas.

La noticia del viaje de los Kastdalen a Galápagos se divulgó en Rjukan, lo que creó gran expectativa en la población, cuyas gentes consideraron a la familia de viajeros como aventureros y bravos, y los llamaban los últimos vikingos.

El padre de Alf decidió que sería "chacrero" en la Isla Santa Cruz, de modo que adquirió lo indispensable para este fin, y junto con su esposa y el pequeño Alf emprendieron viaje desde Oslo hacia Guayaquil, en calidad de colonos, autorizados por el Gobierno ecuatoriano para ir a Galápagos.

La embarcación que debía llevarles de Guayaquil a Galápagos era un viejísimo motovelero de 100 toneladas, comandado por dos capitanes, que cargado como un arca llena de animales de toda especie, de gentes diferentes y de toda suerte de artículos, llegó a San Cristóbal tras seis días de navegación en los que se mezclaron el temor, los rezos y el mareo. Dos días más tarde zarparon hacia Santa Cruz, donde los Kastdalen pusieron sus pies el 10 de agosto de 1935, dos días antes del décimo aniversario de nacimiento de Alf.

Días más tarde, con toda la carga, subieron hacia la parte húmeda de Santa Cruz; se hospedaron en la chacra de sus paisanos Hornemann, y de allí Torbal Kastdalen exploró tierra apta para estable-

cerse. La halló cerca, hacia el Noreste de Fortuna, en un lugar que él llamó Miramar, unos 300 metros sobre el nivel del mar.

Santa Cruz se convirtió en la segunda patria de los Kastdalen; allí creció Alf, envejecieron sus padres, criaron sus animales y plantaron sus vegetales. En Santa Cruz echó raíces la esperanza de Alf, pues jamás retornó a Noruega y tan sólo salió seis veces a la parte continental ecuatoriana. Se casó en enero de 1969 con Corina Espín, colona ecuatoriana que llegó en 1963, con quien tuvo sus hijos Torbaldo y María Corina (de 14 y 12 años en la actualidad).

Alf escribió en 1964 un informe sobre sus observaciones de los cambios en las condiciones biológicas de Santa Cruz, trabajo que fue publicado por la Fundación Darwin en la revista Noticias de Galápagos No. 35, año 1982.

Entre los eventos del fenómeno El Niño 1982-83 fue notable, a más de la abundante lluvia (como se verá en los datos de varios de los artículos de este volumen), la serie de tempestades tropicales. Mucha gente en Santa Cruz jamás había visto un rayo o escuchado un trueno, por lo que estuvieron verdaderamente asustados los días o noches de tempestad. Uno de esos rayos cayó el 20 de junio de 1983 en el transformador eléctrico de la casa de la familia Kastdalen y tiró la línea a tierra. Alf se encargó de la limpieza de la maleza para levantar la red eléctrica; pero, mientras cortaba unas ramas su machete tocó el cable eléctrico de alta tensión, y cayó fulminado por la descarga. Esto ocurrió el 22 de junio de 1983, y se segó así la vida del naturalista, del amigo, del humanista Alf Kastdalen.

La Fundación Charles Darwin para las Islas

Galápagos y su Estación Científica dedican este volumen acerca del fenómeno El Niño 1982-83 a Alf Kastdalen.

Quito, 7 de mayo 1984

Juan Black M.
Secretario General
Fundación Charles Darwin
para las Islas Galápagos

PARTE I

OCEANOGRAFIA

OCEANOGRAPHY

**EL FENOMENO EL NIÑO Y SUS EFECTOS
EN EL CLIMA DEL ECUADOR**

Plutarco Naranjo
Casa de la Cultura Ecuatoriana
Sección de Ciencias Biológicas
y Naturales
Quito, Ecuador

Resumen

La profunda alteración Océano Pacífico - atmósfera, denominada fenómeno El Niño, por lo menos en dos de sus principales manifestaciones: aumento de la intensidad de las olas o marejadas y aumento de las lluvias ha sido conocido en las costas occidentales de Sud América desde tiempos inmemoriales.

El fenómeno Niño se caracteriza por la presencia de una gran masa de agua supercalentada en la zona ecuatorial del Pacífico central y oriental y que afecta en forma directa a las costas de Ecuador y Perú. En los años de Niños muy intensos su influencia puede ir hacia zonas más alejadas y quizá provocar o coincidir con alteraciones climáticas globales.

El Niño aparece irregularmente en períodos que van de tres hasta más de quince años y su intensidad y repercusiones varía de uno a otro. En el Ecuador a más de las alteraciones de flora y fauna marítima una de las consecuencias del Niño es el aumento de las lluvias, en particular desde la línea ecuatorial hacia el sur. Se afecta, por consiguiente, la región comprendida entre las provincias de Manabí y El Oro. Cuando El Niño es muy intenso aumentan las lluvias también en la región interandina.

El Niño 1.982-83 fue el de mayor intensidad que se ha registrado a lo largo de los últimos 100 años. Fue la causa de una profunda alteración climática global o fue parte de ella, que se caracterizó por grandes sequías en ciertas partes del globo y en otras por torrenciales aguaceros e inundaciones. En el Ecuador tuvo profundas consecuencias. En el área de Guayaquil las lluvias alcanzaron un total de 3.949 mm en 1983, cuando el promedio es de sólo 1.100 mm; es decir, que llovió 2,37 veces más que lo normal y se produjeron grandes inundaciones. En Quito las lluvias aumentaron en un 25%.

Summary

The profound Pacific Ocean - atmosphere disturbance referred to as El Niño phenomenon, has been historically known on the western coasts of South America for two of its manifestations: the augmented intensity of waves or tides and the increased rainfall.

The Niño phenomenon is characterized by the presence of a large mass of anomalously warm water in the equatorial central and eastern Pacific which directly affects the coasts of Ecuador and Peru. In very intense Niño years, its influence can reach more distant regions and perhaps provoke or coincide with global climatic perturbations.

El Niño appears irregularly in periods of three to more than fifteen years and its intensity and repercussions vary between events. In Ecuador, besides alterations in the marine flora and fauna, one of El Niño consequences is the increase in rainfall, particularly from the equator to the south. Consequently, it affects the region comprised between the provinces of Manabí and El Oro. When the El Niño is very intense, the

interandean region also receives increased rainfall.

The 1982-83 El Niño was the strongest event that has been recorded in the last 100 years. It was implicated in a profound global climatic perturbation that was characterized by droughts in certain regions and by torrential rains and floods in other parts. In the area of Guayaquil, total rainfall reached 3949 mm in 1983, when the average is only 1100 mm annually. That is, it rained 2.37 times above normal and produced great floods. In Quito, the rains increased 25% over normal.

ANTECEDENTES HISTÓRICOS

Las excavaciones y otros hallazgos arqueológicos a lo largo de la costa noroccidental de Sud América, desde Esmeraldas, al norte del Ecuador, hasta el sur del Perú, arrojan indicios de que algunos poblados fueron abandonados por sus moradores en forma misteriosa, hace muchos siglos. Algunos arqueólogos consideran que este abandono pudo estar ligado a cambios climáticos profundos como los que se han registrado ya en la época histórica, varios de ellos ligados a lo que se conoce como el fenómeno El Niño. El arqueólogo Moseley (citado por Stuller 1984), por ejemplo, sustenta la teoría de que en el año 1.100 antes de Cristo, un fenómeno Niño destruyó el amplio y eficiente sistema de canales de irrigación de la costa norte peruana. Cualquiera que haya sido el motivo del abandono hay un hecho histórico, el descubrimiento por parte de Humboldt, cuando recorrió Sud América, de un gran poblado abandonado, la ciudad de los Chimúes (von Hagen, 1957).

Cuando los españoles empezaron a navegar con

endebles embarcaciones de vela, por el que llamaron Mar del Sur y que más tarde sería rebautizado con el nombre de Océano Pacífico, recibieron informaciones de los aborígenes, de que en dicho mar los vientos soplaban periódicamente desde la costa hacia el mar y en otras ocasiones en sentido inverso. Así mismo recibieron información de que en ciertas épocas del año los vientos se volvían tan tenues que no era posible la navegación a vela. Los intrépidos conquistadores muy pronto confirmaron la verdad de las informaciones y procuraron acomodar sus viajes a las épocas de vientos favorables.

Quizá la primera información histórica más ostensible acerca del régimen de los vientos y corrientes marítimas corresponde al viaje realizado por Fray Tomás de Berlanga, Obispo de Castilla de Oro, y a quien el Emperador Carlos V nombró Visitador del Perú. Desconociendo las informaciones antes mencionadas o desoyendo consejos, lo cierto es que Fray Tomás de Berlanga se hizo al mar, desde Panamá, el 23 de febrero de 1.535 (Larrea 1980). Al octavo día de navegación cesaron por completo los vientos y la corriente marítima comenzó a arrastrar la nave hacia el occidente, sin rumbo ni destino ciertos. Para la buena suerte del nuevo Visitador del Perú y su tripulación, la nave fue a dar con las costas de una isla, el 10 de marzo, a la altura aproximada de 30 minutos geográficos al sur de la línea ecuatorial. La casualidad convirtió a Fray Tomás de Berlanga en el descubridor del Archipiélago de Galápagos, actualmente denominado Provincia de Galápagos de la República del Ecuador.

En los siglos siguientes llegó a ser conocimiento de dominio general el hecho de que a partir de abril o mayo predominaban los vientos que soplan desde el continente (desde la costa del Ecuador y Perú) hacia el mar y que hacia fin de año cesan los vientos o inclusive se invierte su

dirección. Concomitantemente con estos fenómenos atmosféricos, alrededor de diciembre o enero las costas de la región noroeste de Sud América son bañadas por aguas calientes. Como el fenómeno coincidía con la celebración del nacimiento del Niño Jesús, se dio en llamar a este fenómeno "Corriente del Niño".

También desde la época precolombina debió ser conocido el hecho de que en ciertos años se producían lluvias torrenciales mientras en otros se registraba una intensa sequía. Stothert, en una conferencia dictada en el museo Arqueológico del Banco Central, Quito en 1.983, relató que en la península de Santa Elena se han descubierto diques o albarradas construídas hace nada menos que 2.000 años, por los hombres de la llamada cultura Guangala. Esas grandes represas sirvieron para formar reservorios de agua en sitios apropiados. Era agua de lluvia que se desplazaba por cauces que por varios años permanecían secos y se reactivaban en años de lluvias intensas llevando abundante líquido que debía servir para el consumo humano por un período más o menos prolongado, según el tamaño de la población.

En la zona fluminense del litoral, entre Babahoyo y Quevedo, sujeta a inundaciones, los hombres de la cultura precolombina Milagro-Quevedo desarrollaron un amplio sistema de zanjás y camellones (Lumbreras 1981) que les permitía, como en el antiguo Egipto, convertir la inundación en un factor favorable para su agricultura.

En la época colonial en Quito, capital de la Real Audiencia, su Cabildo, en vez de construir diques y reservorios, optó por el más fácil arbitrio de rogar clemencia divina, cuando los rigores climáticos ponían en riesgo la vida de la ciudad. Eligió a la Virgen de Guadalupe como

patrona del buen clima y a ella recurría la ciudad entera cuando el año era o muy lluvioso o muy seco.

El libro de las Actas del Cabildo resulta el primero y más curioso registro climatológico de esta ciudad (Naranjo 1981). Revisando como ejemplo, un simple decenio, el que va de 1.650 a 1.660, se encuentra lo siguiente:

1.650, enero 31. Resolución del Cabildo para traer de Guápulo a la Virgen de Guadalupe para impetrarle mandase las lluvias. Se deduce que 1.650 fue un año muy seco. Desde septiembre hasta el 31 de enero, en años normales se produce aproximadamente el 40% de las precipitaciones anuales.

1.651, enero 24. Igual resolución por igual pedido. Es decir, se trata de un segundo año en el que se prolonga la sequía.

1.651, agosto 11. Resolución para que se traiga a la Virgen para hacer una rogativa pidiéndole "buen tiempo". Es decir, para pedirle que vuelvan las lluvias a partir del siguiente mes, cuando normalmente debe comenzar la estación lluviosa.

1.653, marzo 24. Resolución para que se traiga a la Virgen para implorarle "cesen los temporales". Aunque marzo y abril son los meses más lluviosos en Quito, se deduce que ese año fue excesivamente lluvioso.

1.653, septiembre 16. Nueva resolución para traer en un mismo año, por segunda vez a la Virgen, para pedirle que cesen las lluvias, pues: "los trigos están por recoger"; extraña afirmación. Desde remotas épocas los aborígenes sabían que debía echarse la simiente

entre septiembre y octubre es decir al comienzo de la estación lluviosa, y el maíz estaba listo para la cosecha en junio, cuando se celebraba una de las grandes festividades. Fechas que aproximadamente coincidían con otras del calendario cristiano y fueron convertidas en celebraciones católicas. El que en septiembre estuviesen los "trigos por recoger" significa una siembra tardía, a destiempo o que en razón de las abundantes lluvias, no pudieron ser recogidos oportunamente, a esperas de que las plantas se secasen. De todos modos, 1.653 debió ser un año anormalmente lluvioso y de grandes pérdidas agrícolas.

1.656, enero 12. Bajo pedido del nuevo Presidente de la Real Audiencia de Quito, el Cabildo proclama un nuevo patrono del tiempo, San Miguel es el escogido, pero lo que antes sucedió con los aborígenes ahora sucede con los propios españoles y criollos. Una fe no se impone por decreto. La devoción continuó para la Virgen de Guadalupe y el pobre San Miguel nunca llegó a ser un verdadero patrono del clima de Quito, más bien en años siguientes se propagó el fervor por la Virgen del Quinche.

1.657, junio 19. Resolución para que se traiga a la Virgen del Quinche para pedirle cesen las muchas lluvias y desaparezca la grave epidemia de viruelas. Por segundo año consecutivo debió llover en exceso, pues junio es mes que normalmente llueve poco. Una resolución de rogativa tomada el 19 de junio significa que aún seguía lloviendo "a cántaros".

En conclusión, desde muy antiguo se han identificado dos fenómenos: uno atmosférico, relacionado con los cambios de la dirección e intensidad de los vientos, y otro oceánico con el aumento de la tempe-

ratura del agua entre diciembre y los primeros meses de cada año. También desde épocas muy remotas se ha conocido la alternancia irregular de años muy lluviosos, que aparecen sin ninguna periodicidad.

QUE ES EL NIÑO

El fenómeno El Niño conocido y definido como un evento oceánico, consiste en la presencia, especialmente notoria en la costa noroccidental de Sud América de una gran masa de agua caliente y de baja salinidad. En las costas de la República del Ecuador la temperatura de esta masa de agua oscila, según El Niño, entre 23 - 30 grados C. y una salinidad de sólo 32 a 33 por mil.

El fenómeno aparece usualmente en la segunda quincena del mes de diciembre, pero puede comenzar tempranamente en noviembre o retrasarse hasta enero. La temperatura del agua asciende en forma progresiva durante uno a dos meses y luego, en los dos o tres meses siguientes, vuelve a los valores iniciales. El fenómeno Niño en ciertos años es muy intenso y de graves repercusiones para la vida marítima y aún terrestre, mientras en otros es débil o imperceptible.

Las investigaciones realizadas en los últimos años (Cane 1983; Rasmusson y Wallace 1983) revelan que el Niño ni es sólo un fenómeno oceánico ni mucho menos restringido a solamente el área de la costa noroccidental de Sud América. Tales investigaciones demuestran la estrecha interacción que existe entre océano y atmósfera y obligan a redefinir al Niño en términos tanto oceánicos como atmosféricos y climáticos. En efecto, El Niño es la exacerbación, en el Pacífico tropical, del ciclo de fluctuación acoplada océano-atmósfera con las consiguientes alteraciones climáticas que pueden repercutir en amplias regiones tropicales y aún extratropicales.

COMO SE GENERA

Desde hace mucho tiempo se ha especulado acerca de cómo se origina el fenómeno Niño y se han formulado diversas hipótesis y teorías. Bjerkness (1966), quien estudió el fenómeno Niño de 1.957-58, 1.963-64 y 1.965-66 y analizó la interacción océano-atmósfera, llegó a la conclusión que los eventos en gran escala que se producen en el Océano Pacífico ecuatorial son causados por una interacción entre el océano y la atmósfera, y que además estos fenómenos no quedan localizados en sólo la franja ecuatorial sino que tienen o pueden tener consecuencias globales. Tanto estos estudios como los de Montgomery (1968) y otros autores, llegan a la conclusión de que el océano y la atmósfera forman un solo sistema, con interacción recíproca; es decir, se trata de un sistema muy dinámico en el cual pueden influir diversos factores, algunos de los cuales han sido ya estudiados.

Según las investigaciones efectuadas en los últimos años en el Pacífico ecuatorial, existen dos zonas con presión atmosférica muy distinta: hacia el lado de la costa de Sud América está la zona de alta presión, en tanto que al otro extremo del océano, cerca de Indonesia, se encuentra la zona de más baja presión atmosférica. Pero estas condiciones predominan sólo en parte del año, de modo que hay una oscilación entre los dos extremos, a la que se ha dado en llamar "oscilación sureña". Los vientos alisios soplan desde Sud América hacia el Pacífico central en los meses de junio a noviembre, disminuyen en intensidad entre noviembre y diciembre, y luego pueden inclusive cambiar de dirección.

La gradiente de presión a lo largo del Pacífico ecuatorial determina que a nivel de las costas de Sud América el nivel del océano sea más bajo, en tanto que al extremo occidental, por cerca de Nueva

Guinea e Indonesia, el nivel del océano aumenta entre 10 a 20 cm, pero en Niños intensos puede subir hasta en un medio metro (como cuando en un recipiente de agua se sopla en un extremo y pierde nivel mientras se eleva al otro extremo). Al cesar la presión, el agua tiende a recobrar el nivel original.

El área de los cambios más intensos se localiza entre la costa sudamericana y el meridiano 140 grados Oeste y desde el paralelo 3 grados Norte hasta el paralelo 15 grados Sur. Esta área de Pacífico ecuatorial es normalmente más fría que el resto del océano intertropical. El mayor flujo de agua que recibe el área descrita proviene de la corriente fría de Humboldt, llamada también corriente del Perú, que moviliza una gigantesca masa de agua. La anchura de esta corriente oscila entre 200 y 300 km y se desplaza a lo largo de la costa sudamericana bañando el norte de Chile, el Perú y alcanza hasta cerca de la línea ecuatorial en el mar ecuatorial, desde donde cambia de rumbo hacia el occidente en dirección al Pacífico central. La corriente sur ecuatorial, que impulsada por los vientos alisios fluye también hacia el Pacífico occidental, es de agua tibia y en su largo recorrido por la zona tropical se calienta de modo progresivo alcanzando una temperatura alta. Al cesar los alisios se debilita la intensidad de esta corriente.

En la dinámica del sistema océano-atmósfera participan también otras corrientes, como la llamada contracorriente ecuatorial del Pacífico que moviliza por segundo millones de metros cúbicos de agua tibia desde el Pacífico occidental hacia la costa de Sur América, y la corriente de Cronwell. También intervienen factores atmosféricos como la llamada convergencia intertropical, la movilización de la llamada frente ecuatorial, así como la convergencia subtropical del Pacífico sur.

Entre noviembre y diciembre la zona de convergencia intertropical, en el Pacífico occidental tiende a movilizarse hacia el norte y el este, al tiempo que cesan los vientos alisios que soplan desde la costa sudamericana hacia el Pacífico central, disminuyendo la alta presión del lado de la costa sudamericana, todo lo cual contribuye a que las aguas que habían sido empujadas en dirección occidental hacia la zona de los archipiélagos, entre los cuales está el Indonésico, tienden a regresar en dirección al continente americano. Las olas u ondas de Rossby que se desplazan desde las costas sudamericanas hacia el Pacífico occidental pierden altura, fuerza y velocidad al tiempo que las ondas ecuatoriales de Kelvin que se desplazan hacia las costas sudamericanas adquieren mayor altura y velocidad, a tal punto que pueden cruzar el Pacífico en sólo tres meses.

Al mismo tiempo, las aguas superficiales van en forma progresiva aumentando su temperatura, mientras disminuye la salinidad. La termoclina se profundiza. La isoterma de 20 grados C, por ejemplo, que en noviembre no alcanza ni a 50 m de profundidad, en enero o febrero puede alcanzar hasta más de 100 m y en Niños intensos puede sobrepasar ampliamente este nivel, como sucedió en El Niño de 1982-83.

Se forma así una gran lengua de agua caliente que se extiende a lo largo de la franja ecuatorial; la amplitud y profundidad varía según los años. También contribuye al calentamiento del océano, por debajo de la línea ecuatorial, el calor del verano del Hemisferio Sur que entre otros factores determina que la corriente de Humboldt se entibie. La exacerbación de esta oscilación anual constituiría el fenómeno Niño.

Según Cane (1983), un Niño muy intenso puede preverse aproximadamente con 18 meses de

anticipación. El signo premonitorio estaría constituido por los vientos en el Pacífico occidental. En efecto, hasta con 18 meses de antelación, es posible registrar vientos en dirección a Sud América, con intensidad creciente y cuya fuerza dinámica es transmitida a la superficie del océano.

Los fenómenos mencionados anteriormente dan como consecuencia la disminución del nivel del Océano Pacífico occidental, mientras en forma equivalente se produce el aumento del nivel en las costas sudamericanas. Tal aumento afecta sobre todo al Ecuador y al Perú, pero en forma decreciente afecta a zonas más amplias tanto al norte como al sur. En Niños intensos, este aumento de nivel puede percibirse tan lejos hasta en las costas de California. El aumento de nivel, según su magnitud, puede acompañarse de marejadas.

El incremento de la temperatura del mar se acompaña de mayor evaporación, y esto a su vez determina la formación de nubes densas y las consiguientes lluvias, entre fines de diciembre y el mes de abril. En Niños intensos las lluvias aumentan en intensidad y se prolongan por uno o más meses, dando valores totales hasta el doble y triple que los años normales. Como es de suponerse, las grandes tempestades producen graves inundaciones, desbordamiento de ríos y otros trastornos físicos y ecológicos. Las mayores tempestades se producen en el propio océano, en el Pacífico central, pero el área de influencia se extiende hacia Sud América y otras regiones del planeta.

Entre abril y mayo, en los años normales, vuelven a soplar los vientos alisios desde la costa sudamericana hacia el occidente. Hay aumento de la presión atmosférica en el lado sudamericano, mientras al otro extremo del Pacífico hay disminución y así se inicia la otra fase del ciclo de oscilación sureña.

En años de Niño y, mientras más intenso peor, la franja oceánica tropical se sobrecalienta, sube exageradamente de nivel en las costas sudamericanas, la temporada lluviosa se prolonga y la segunda fase del ciclo de oscilación sureña se retarda.

EL FENOMENO NIÑO Y EL CLIMA DEL ECUADOR

El territorio de la República del Ecuador, pese a su pequeña extensión (280.000 km cuadrados) tiene una amplia variedad de climas ecuatoriales. Se debe a que sus costas están influenciadas por el sistema océano-atmósfera, mientras la región interandina, constituida por dos cadenas principales de montañas altas que recorren el país de norte a sur, es decir paralelamente a las costas, está bajo influencias de otros factores meteorológicos, y la región oriental o trasandina participa del régimen climático de la hoya amazónica.

El período de lluvias, para restringir esta breve revisión a sólo el régimen pluvial, en la costa ecuatoriana se inicia entre noviembre y diciembre, aumenta en forma rápida durante el mes de enero y llega al máximo entre febrero y marzo. En abril cae la curva de lluvias casi en línea vertical y termina en el mes de mayo. Este régimen, como puede verse para Guayaquil en la figura 1, es típico de la costa ecuatoriana desde la línea ecuatorial hacia el sur; al norte, como en Esmeraldas, según puede verse en la figura 1, la curva de lluvias disminuye de modo progresivo desde el mes de febrero hasta noviembre, para volver a subir a partir de este mes. Las hoyas interandinas cuyo sistema fluvial desagua en el Pacífico, como la de Quito por ejemplo, tienen régimen de lluvias muy distinto.

La estación lluviosa es denominada en el Ecuador "invierno", pero como en la costa coincide con el aumento de la temperatura del océano y el consiguiente

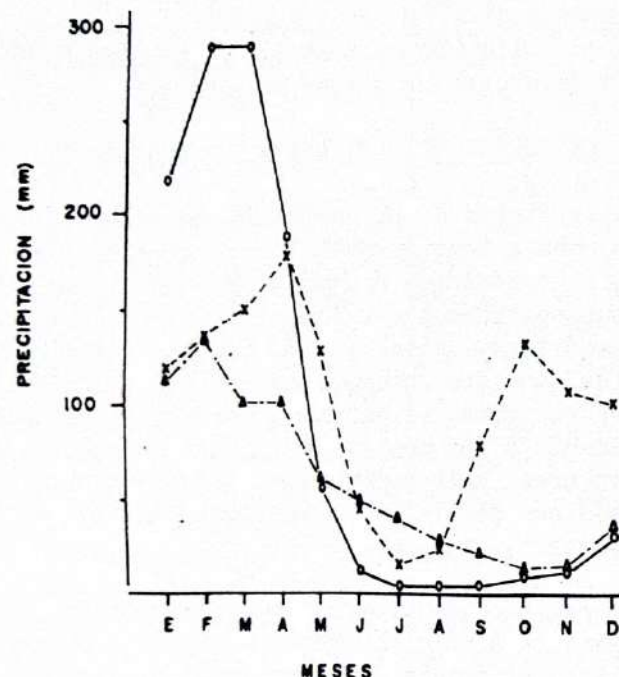


Figura 1. Régimen de lluvias de Guayaquil (círculos), Esmeraldas (triángulos) y Quito (equis). La figura muestra los promedios mensuales de precipitación de los últimos 40 años (basado en datos del Instituto Nacional de Meteorología e Hidrología). La hoya del río Guayas y parte del Golfo de Guayaquil tienen un clima tropical húmedo, con abundantes lluvias entre enero a abril de cada año. La parte norte del litoral ecuatoriano tiene escasas lluvias que se concentran de enero a abril, pero en Esmeraldas el régimen es un poco diferente y aunque febrero es el mes más lluvioso, hay lluvias todo el año. En las hoyas interandinas que desaguan al Pacífico, como la de Quito, las lluvias se incrementan de enero a abril, luego descienden entre mayo y agosto para aumentar en los meses siguientes del año.

te aumento de la evaporación, es también la época de mayor calor y de mayor humedad atmosférica.

En el régimen de lluvias de la costa del Ecuador seguramente influye de modo determinante la oscilación sureña. El tipo de régimen es bastante constante, pero la cantidad anual de precipitaciones varía dentro de muy amplios márgenes. Por ejemplo, en Guayaquil llovió menos de 400 mm en 1.968, mientras en 1.976 excedió de 1.800 mm; es decir, más de cuatro veces de diferencia entre los dos años extremos. En el régimen pluvial del sur del litoral debe influir también la corriente de Humboldt, que como se mencionó ya, es de agua sumamente fría. No permite sino muy escasa evaporación, a tal punto que no se forman nubes densas, y las costas sometidas a su influencia directa, desde la mitad norte de Chile hasta el norte del Perú se han convertido en uno de los más pelados desiertos del mundo. La corriente influye de modo parcial sobre la costa ecuatoriana, pues pasa más alejada de ella que lo que sucede en el Perú, y aproximadamente a la altura de un grado de latitud Sur se desvía hacia el occidente. En los meses de invierno del Hemisferio Sur, la corriente es más fría; así mismo lo es el Golfo de Guayaquil, hay algo de niebla pero no lluvias y es la época que en nuestro territorio se denomina "verano". Durante el verano del Hemisferio Sur, la corriente de Humboldt se entibia un poco y las aguas del océano que baña nuestras costas, tanto por el aumento de la irradiación solar cuanto por el reflujo de la oscilación sureña, aumenta de temperatura, aumenta la evaporación y se producen las lluvias.

LOS CICLOS DEL NIÑO

Mucho se ha especulado acerca de la periodicidad del fenómeno Niño. Podría afirmarse que hay tantos ciclos o períodos como autores. Hay quienes afirman que El Niño reaparece en ciclos de dos o tres años,

mientras otros extienden a cuatro o cinco años, faltando quienes suponen que los ciclos son de siete años y otros de quince. En parte, la confusión debe a que el fenómeno Niño, aunque está y es caracterizado en forma cualitativa, no está evaluado en términos cuantitativos y de modo genérico habla de Niños intensos y débiles. Así y todo, los registros climatológicos de varios de los servicios especializados de Estados Unidos, con datos desde 1.875 como puede verse en la tabla 1, demuestran que el fenómeno Niño no es cíclico, reaparece irregularmente con intervalos que pueden ir desde dos años hasta más de quince.

Hace poco el Comité Científico de Investigación Oceánica de los Estados Unidos de América (Can 1983), propuso una definición cuantitativa de un "Niño Mayor". Sería aquel asociado a un aumento de la temperatura superficial del mar en por lo menos tres de cinco estaciones costeras situadas entre 5 grados Sur (Talara, Perú) y 12 grados Sur (Callao, Perú). El aumento de temperatura debe exceder una desviación estándar durante cuatro o más meses consecutivos.

El poder anticipar siquiera con unos meses el fenómeno Niño y su intensidad sería de inmensa utilidad práctica a fin de adoptar, por lo menos dentro de ciertos límites, medidas preventivas contra el exceso de precipitaciones, inundaciones, etc. Si el fenómeno fuese cíclico sería fácil predecir el año en que va a producirse un nuevo fenómeno Niño por desgracia, aparece con frecuencia irregular y por tanto es indispensable estudios adicionales que permitan su pronóstico.

La tabla 1, en la que se indican los años de Niño intenso desde 1.875, confirma que su aparición no es regular y permite, en cuanto se refiere al clima del Ecuador, visualizar lo siguiente: (1) Lo

Tabla 1. Años del fenómeno El Niño y los más lluviosos en Guayaquil, Esmeraldas, Quito.

Año	Niño Intenso*	Porcentaje de exceso lluvia**		
		Guayaquil	Esmeraldas	Quito
1940		35		
1941	X	45		
1943		36		24
1944			20	
1947			33	
1950			34	33
1951			38	18
1953		64	43	31
1954				13
1955				16
1957		40		
1958	X	34		
1959			90	
1965	X	18		
1969				11
1971				18
1972		27	34	16
1973	X	25	24	
1975		40		24
1975	X	68	47	
1977			13	
1982			5	11
1983	X	237	132	25

* Según registros de los Estados Unidos de América (Stuller 1984).

** Porcentaje de exceso sobre el promedio de 40 años: Guayaquil, 1120 mm; Esmeraldas, 760 mm; y Quito, 1250 mm (Basado en datos del Instituto Nacional de Meteorología e Hidrología, Quito).

años de fenómeno Niño influyen en la intensidad de las lluvias en la costa, pero sobre todo desde la línea ecuatorial hacia el sur. Durante los Niños 1.940-41, 1.957-58, 1.965, 1.972-73, 1.976-77, en Guayaquil hubo un incremento de lluvias que fue desde un 18% hasta más del 80% sobre el promedio de los últimos 40 años. (2) Hay años en los que en la región de Guayaquil llueve intensamente, como en 1.945 y 1.953, sin que en los Servicios Meteorológicos de Estados Unidos de América se haya registrado la presencia del Niño. (3) La región norte de la costa, como la zona de Esmeraldas por ejemplo, sufre la influencia de los Niños más intensos, pero de modo independiente de ellos pueden producirse años lluviosos. (4) Las zonas interandinas, tomada como ejemplo la de Quito, sufren la influencia del Niño sólo cuando éste es muy intenso, como en los años 1.972 y 1.982-83, de lo contrario los años de sequía o de lluvia intensas se producen de modo independiente de la oscilación sureña y de la presencia del Niño.

EL NIÑO DE 1.982-83

El Niño 1.982-83, tanto por su duración cuanto por el desarrollo tecnológico, incluyendo la participación de barcos, aviones y satélites meteorológicos de Estados Unidos de América y de otros países, ha sido el mejor estudiado a lo largo de la historia de la humanidad.

El año climático 1.982-83 fue uno de profunda alteración del clima de todo el globo terrestre. Si esta alteración global del clima fue debida al Niño o si el fenómeno Niño fue parte de esa alteración global, es algo relativo que no se ha discutido suficientemente.

A partir de junio de 1.982 y por el lapso aproximado de un año, se produjeron profundas

alteraciones climáticas, entre las cuales hay que mencionar: terribles tormentas en Hawaii; en Tahití los peores huracanes de los que haya noticias; un verano muy caluroso en las Montañas Rocosas de Estados Unidos de América; gran sequía en el centro sur de Estados Unidos, mientras California era azotada por marejadas y tormentas durante el invierno; Australia registró la peor sequía de su historia; parte de Nueva Zelanda, Indonesia, Filipinas, el sur de la India, Sri Lanka y el sur del África sufrieron así mismo una desastrosa sequía, mientras en Francia y norte de Italia se registraron lluvias excesivas y sobre todo en el sur de Brasil, en Uruguay y norte de Argentina; en el Perú hubo lluvias torrenciales y grandes inundaciones en la parte norte, mientras el sur del país sufría las consecuencias de la sequía (Stuller 1984).

Entre fines del mes de Mayo y comienzos de junio de 1.982, de modo inesperado comenzó a aumentar la presión atmosférica en el Pacífico central, al tiempo que disminuía a lo largo de las costas sudamericanas, desde la latitud ecuatorial hacia el norte y sobretodo hacia el sur, en dirección a la costa peruana, en una extensión de varios miles de kilómetros. Los vientos que por esa época soplan desde el continente hacia el Pacífico central, disminuyeron en intensidad y las aguas comenzaron a sobrecalentarse. Hacia diciembre se registraba ya la presencia de una gigantesca masa de agua caliente en forma de una lengua muy alargada, cuya base iba desde la costa del Golfo de Panamá hasta la mitad norte del Perú y su ápice alcanzaba las cercanías de Nueva Zelanda e Indonesia. El centro térmico, es decir de sobrecalentamiento del agua con un aumento de más de 5 grados C, se ubicó siguiendo la línea ecuatorial entre los meridianos 110 y 130 grados Oeste. Esta gigantesca lengua de agua caliente alcanzó más de 13.000 km de longitud en el mes de diciembre de

1.982 y se retrajo hacia las costas sudamericanas, pero en julio de 1.983 todavía alcanzaba una extensión de 5.000 km. En julio la temperatura de más de 5 grados C sobre lo normal, de las aguas superficiales, había disminuido a 2 o 3 grados C en el Pacífico central. En las cercanías de las costas sudamericanas para el mismo mes había descendido de 7 a 5 grados C (Stuller 1984).

Las numerosas investigaciones realizadas en escala mundial sobre El Niño 1.982-83 se encuentran resumidas principalmente en las publicaciones de Cane (1983), en lo referente a los aspectos oceanográficos; Rasmusson y Wallace (1983) en lo que se refiere a las alteraciones meteorológicas, y en la de Barber y Chavez (1983) sobre los cambios de temperatura y composición química del océano y sus profundas consecuencias biológicas. Otros estudios sobre El Niño 1.982-83 y otros anteriores se encuentran en las de Wyrski y colaboradores (1981), Weare (1983) y Rasmusson y Hall (1983).

EL NIÑO 1.982-83 EN EL ECUADOR

El Niño de 1.982-83 afectó profunda y gravemente a la República del Ecuador. Se produjeron fuertes y repetidas marejadas que arrasaron varios pequeños poblados, sobre todo en la costa de la provincia de Manabí. La temperatura del agua que en los Niños de los últimos 40 años ha subido en sólo 2 a 3 grados C, en El Niño de 1.982-83 se elevó cerca de 10 grados C y este sobrecalentamiento se prolongó hasta septiembre de 1.983. En los primeros días de este mes, la temperatura del agua en el Golfo de Guayaquil aún era de 26 grados C y recién a mediados de este mes comenzó a bajar. A mediados de octubre había descendido a 19 grados C a lo largo de las costas y a 22 grados C entre éstas y las Islas Galápagos.

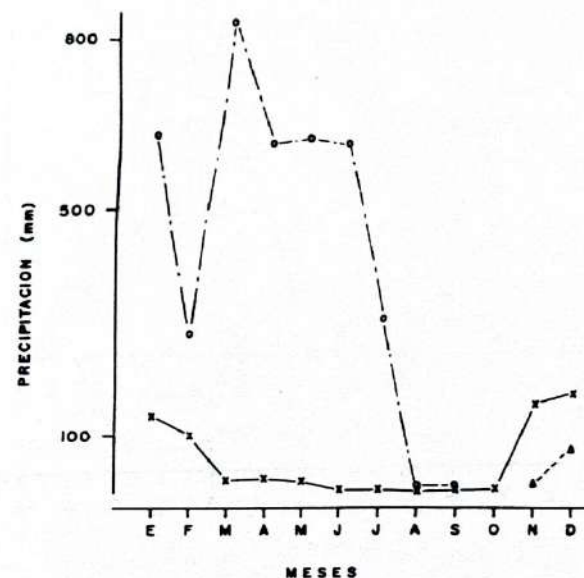


Figura 2. Las lluvias en Guayaquil en El Niño 1.982-83. X—X, 1.982, O—O, 1.983. Como puede apreciarse en el diagrama el año 1.982 hasta el mes de octubre fue anormalmente seco, con muy escasas precipitaciones. En cambio a partir de octubre de 1.982 las precipitaciones aumentaron de modo exagerado, convirtiendo al año meteorológico 1.982-83 en uno de los más lluviosos del siglo.

La temperatura atmosférica fue muy superior a la normal y la estación calurosa se prolongó hasta septiembre-octubre y no solamente en el litoral sino también en la región interandina. En Quito, por ejemplo, en Agosto de 1.983 todavía se registraban temperaturas superiores a las normales. El promedio de ese mes fue de más de 2 grados C de lo normal.

Pero los mayores trastornos ecológicos y económicos, tanto en la sierra como sobre todo en la

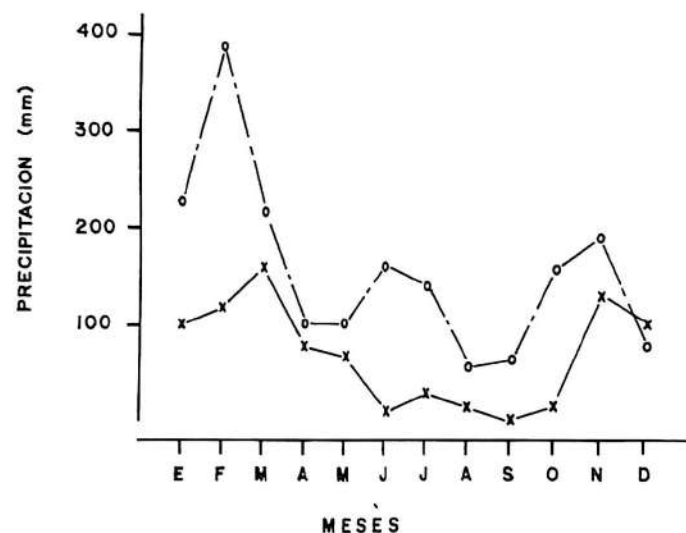


Figura 3. Las lluvias en Esmeraldas en El Niño 1.982-83. X—X, 1.982, O—O, 1.983. Como en el caso de Guayaquil, en Esmeraldas también, las lluvias aumentaron desde octubre de 1.982 a cifras muy superiores al promedio normal y el año meteorológico fue muy lluvioso, aunque en menor proporción que Guayaquil.

región del litoral, se debieron a los torrenciales aguaceros y a la prolongada estación lluviosa, con desbordamiento de ríos, grandes inundaciones, en particular en la extensa y rica hoya del río Guayas, con pérdida de cosechas y ganaderías; también se produjeron marejadas que destruyeron parcialmente los poblados y ciudades ubicadas a la orilla del mar; se destruyó el sistema vial de la costa; en fin, fue el año de las mayores catástrofes en lo que va del siglo.

En las figuras 2 a 4 puede verse el comportamiento de las lluvias en los tres sitios

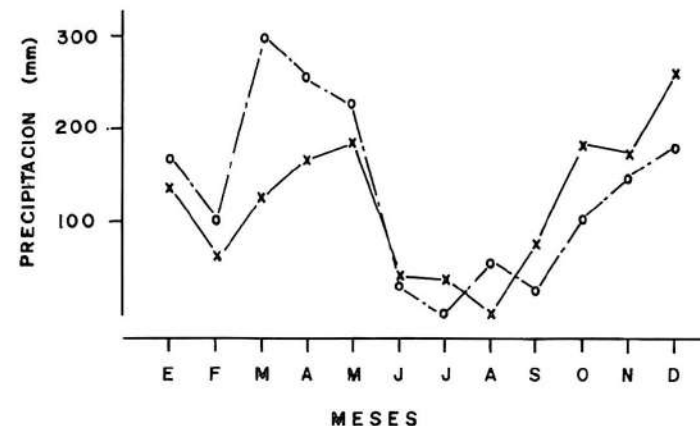


Figura 4. Las lluvias en Quito en El Niño 1.982-83. X—X, 1.982, O—O, 1.983. A partir de septiembre de 1.982 las precipitaciones superaron al promedio de los últimos 60 años y así mismo fueron superiores hasta el mes de mayo de 1.983, pero el exceso de lluvias sólo equivalió, durante el año, a un 25% sobre el promedio.

del país tomados como referencia: Guayaquil, Esmeraldas y Quito. En primer lugar, hay que anotar que el período de lluvias de Guayaquil de noviembre de 1.981 a junio de 1.982 fue de muy escasas precipitaciones, de sólo 668 mm en total, cuando el promedio de los 40 años anteriores es de 1.120 mm. El período de lluvias correspondiente al Niño 1.982-83 comenzó tempranamente en el mes de noviembre, con lluvias que alcanzaron a 152 mm, mientras el promedio es de sólo 5 mm. Fue en aumento hasta enero, amainó en febrero, para llegar al máximo de 830 mm en el mes de marzo y prolongarse hasta el mes de junio, dando un total de

precipitaciones de 3.949 mm; es decir, 2,37 veces más que el promedio normal, constituyéndose en el período más lluvioso que ha registrado esa región del país durante el presente siglo.

Esmeraldas en cambio, tuvo en 1.982-83 un período lluvioso un poco superior al promedio. Durante el año del Niño llovió intensamente, pero mucho menos que en Guayaquil. De 760 mm que es el promedio, subió a 1.766 mm con un régimen o curva anual bastante parecido al normal, pero con más del doble de lo normal de precipitaciones.

En cuanto a Quito, las lluvias del primer ciclo, que corresponden de enero a junio de 1.982 fueron normales; pero, a partir de septiembre llovió más que el promedio, llegando a un máximo de 295 mm en el mes de marzo, cuando el promedio es de 155 mm. El año de 1.983 registró un total de precipitaciones de 1.553 mm, cuando el promedio es de 1.225 mm; es decir, que en Quito durante El Niño hubo un aumento de las precipitaciones de sólo un 25%.

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PACIFIC-WIDE SEA LEVEL FLUCTUATIONS DURING THE
1982-83 EL NIÑO

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Abstract.

Sea level records are used to describe and discuss the response of the sea surface topography of the equatorial Pacific Ocean during the 1982-83 El Niño event. During the second half of 1982 westerly winds over the western Pacific caused a draining of warm water from the area north of the equator and a first peak of sea level at the Galápagos Islands in December. During the first half of 1983 westerly winds to the south of the equator caused draining of warm water from the area between the Solomon Islands and the Marquesas Islands and a second peak of sea level at the Galápagos Islands in May. At the end of El Niño in October 1983 sea level over the entire equatorial Pacific was below normal, indicating a loss of warm water from the equatorial Pacific.

Resumen

Los registros de niveles marinos se utilizan para describir y para discutir la respuesta de la topografía de la superficie oceánica del Océano Pacífico Ecuatorial durante el evento de El Niño 1982-1983. Durante la segunda mitad de 1982, los vientos hacia el oeste sobre el Océano Pacífico Occidental causaron un drenaje de agua caliente desde el área al norte del ecuador y un primer pico de nivel marino en las Islas Galápagos en diciembre. Durante la primera mitad de 1983 los vientos hacia el oeste, al sur del ecuador, causaron un drenaje de agua caliente del área entre las Islas Solomón y las Islas Marquesas, y un segundo pico de nivel marino en las Islas Galápagos en mayo. A finales de El Niño, en octubre de 1983, el nivel marino en todo el Pacífico Ecuatorial estuvo por debajo de lo normal, lo cual indica una pérdida de agua caliente en el Océano Pacífico Ecuatorial.

Introduction.

The El Niño event of 1982-83 started in July 1982 during the southern hemispheric winter, in contrast to most earlier events which started during southern summer. It also became the largest El Niño in recorded history as measured by the size and intensity of the collapse of the tropical wind field and by the reaction of the southern oscillation, as well as by the magnitude of the temperature anomalies observed in the equatorial and eastern Pacific. The occurrence in southern winter was at least partially responsible for the magnitude of the temperature anomalies.

Sea level is a most convenient parameter to monitor the response of the ocean surface to the changing wind systems during this El Niño event. In the frequency range from weeks to years the topography of the sea surface is related to ocean circulation by geostrophy, and consequently sea level differences are a measure of the intensity of the various branches of ocean circulation. Sea level can also document large-scale wave processes, such as planetary waves, and some will be obvious from the data presented in this report. In addition, sea level is also a measure of other oceanographic parameters, like heat content or thermocline topography, the latter especially in the tropical ocean, where the density structure can be approximated by a two-layer system.

Data.

During 1974/75 a network of sea level stations was established on islands in the Pacific to

monitor sea level variations (Wyrтки, 1979a). Data from the 27 stations of this network are used together with data from 8 island-based stations operated by the National Oceanographic and Atmospheric Administration (NOAA) and several coastal stations along the west coast of America (provided by local authorities with the assistance of Dr. D. Enfield of Oregon State University).

The majority of the sea level stations used in this study have only been in operation since 1975 and consequently all data have been referred to the mean sea level (MSL) at each station for the seven-year period 1975 to 1981. The sea level records at Ponape (6°59'N, 158°14'SE), Christmas Island (1°59'N, 157°29'W), Santa Cruz in the Galápagos Islands (0°45'S, 90°19'W), and Funafuti (8°31'S, 179°21'E) are shown in Figures 1 to 4 for the period 1981 to 1983. The curves represent daily mean sea level, which was derived from the original record by eliminating the tides.

Maps of the anomaly of monthly mean sea level have also been produced. They are related to the mean sea level (MSL) at each station for the seven-year period 1975 to 1981. No trends have been removed because of the shortness of this period. In view of the presence of short-term climatic fluctuations with periods of several years the identification and removal of a trend requires data over several decades. Almost all stations show a weak annual cycle, which has been documented by Wyrтки and Leslie (1980). At most stations in the tropical Pacific the amplitude of the first harmonic of the annual cycle is less than 50 mm and would be apparent in charts contoured at that interval. Consequently the mean

annual cycle (MAC) for the period 1975 to 1981 has been computed for each station and has been removed from the sea level values. This procedure results in monthly mean sea level anomalies (SLA), which are defined by the relation

$$SLA = SLH - MSL - MAC,$$

where SLH is the observed monthly mean sea level height.

The mean sea level anomalies have been mapped and the maps illustrate the large-scale response of the sea surface topography of the equatorial Pacific ocean during the 1982-83 El Niño. The maps for July and December of 1982 and for May and October of 1983 are shown as Figures 5 to 8 in this report. All 24 monthly maps for the years 1982 and 1983 have been published by Wyrтки (1984a).

The Sea Level Response in 1982-83.

The response of sea level is forced by the wind field, so it is necessary to discuss first the major changes of the wind field over the tropical Pacific during the 1982-83 El Niño. During the first half of 1982 the trade wind field over the Pacific Ocean was not decisively different from normal (Arkin et al., 1983). Along the equator and east of the dateline winds were slightly stronger than normal and over the western equatorial Pacific bursts of westerly winds were recorded (Sadler and Kilonsky 1983a), but this situation is not uncommon. Starting in late June 1982 westerly winds over the western equatorial Pacific became stronger and more widespread, and by July they reached to the dateline. The patch of anomalous westerly winds moved slowly eastward, covering most of the equatorial Pacific in October and November (Sadler and Kilonsky, 1983b).

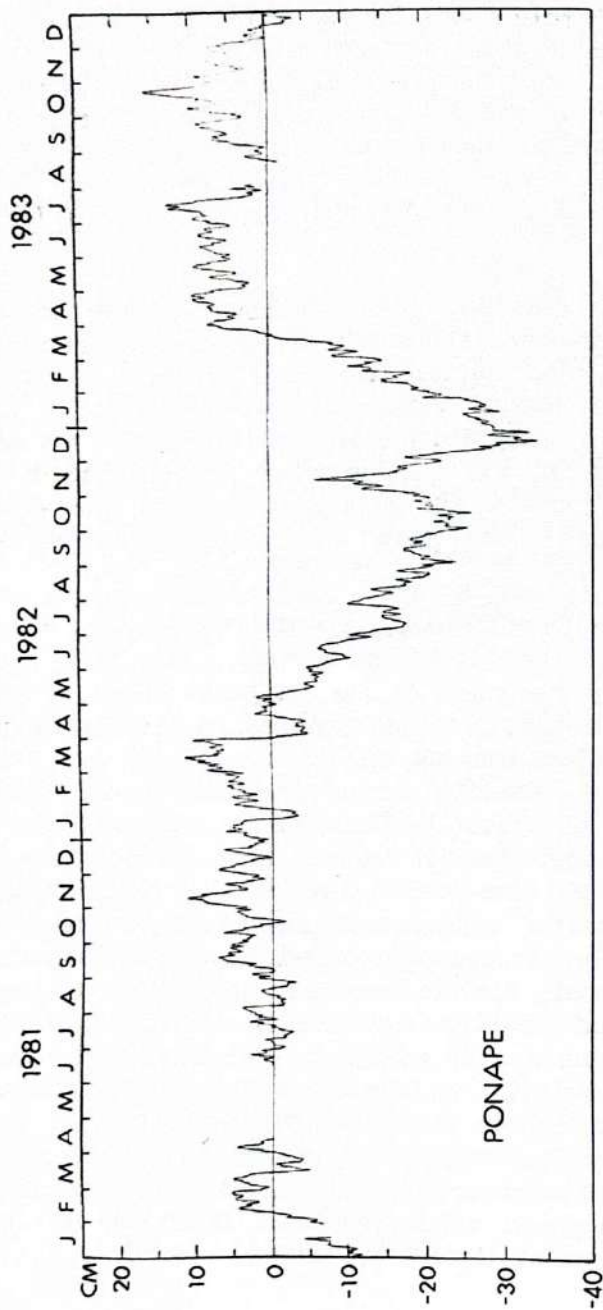


Figure 1. Daily mean sea level at Ponape, from 1981 to 1983 in cm relative to the long term mean.

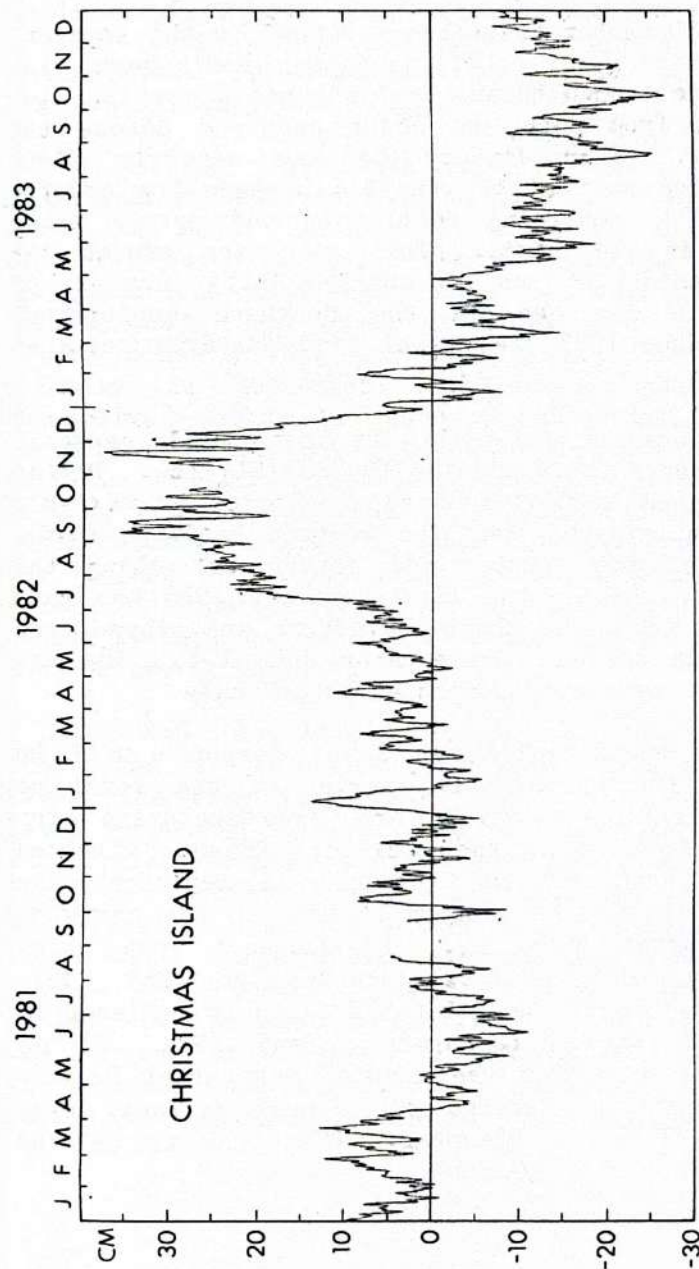


Figure 2. Daily mean sea level at Christmas Island, from 1981 to 1983 in cm relative to the long term mean.

In December the action shifted to the southern hemisphere, as the southern hemisphere low pressure trough became dominant and a massive flow of air from north to south occurred across the equator. From January to May westerly winds dominated most of the Pacific between the equator and 10°S , reversing completely the normal trade winds in this area. This situation caused the development of an unusually large number of tropical cyclones in the southern hemisphere. After June 1983 the normal wind patterns returned again.

In summary one might say that two large-scale wind events dominated the 1982-83 El Niño. During the second half of 1982 a large patch of westerly winds originated over the western Pacific to the north of the equator and moved east along the equator. During the first part of 1983 the path shifted to the southern hemisphere and stayed over the area between the equator and 10°S . The sea surface topography responded accordingly.

The Pacific-wide sea level response will be illustrated by the time series of sea level at four stations, which are representative for selected parts of the Pacific. Ponape, situated in the countercurrent trough, is representative for events in the western Pacific to the north of the equator (Fig. 1). It shows a long, slow decrease of sea level starting in May 1982, reaches a low in December 1982, and is followed by a rapid rise. Christmas Island (Fig. 2) is representative for the central equatorial Pacific and shows the passage of a peak in sea level between July and December. This peak is related

to the surge of warm water from the western to the eastern Pacific along the equator by means of Kelvin waves. After the passage of this surge sea level is markedly below normal.

Sea level at Santa Cruz (Fig. 3) is representative for the eastern equatorial Pacific, where the major effects of El Niño are being felt. It shows virtually the same signal as sea level stations along the coasts of Ecuador, Peru and Colombia. Sea level at Santa Cruz has two small peaks in May and June 1982. It rises markedly in September 1982 and reaches two successive peaks in January and May 1983. Thereafter it decreases rapidly to below normal values. Funafuti represents sea level in the western Pacific south of the equator in an area where normally a high in dynamic topography marks the center of the south Pacific anticyclonic gyre. At Funafuti (Fig. 4) sea level starts to plunge in December 1982 and reaches a low in June 1983 before it rises again.

Although these time series show the changes of sea level at selected locations, they do not reveal the true large-scale patterns of the sea level response. The response patterns are better illustrated by maps of sea level for the entire Pacific. During 1981 and early 1982 sea level at most stations does not deviate significantly from normal over large areas. In the first half of 1982 a weak positive anomaly of sea level is evident in the western Pacific. In the area of the Mariana and western Caroline Islands, along the equator and from the Solomons to Tahiti, positive anomalies between 5 and 10 cm

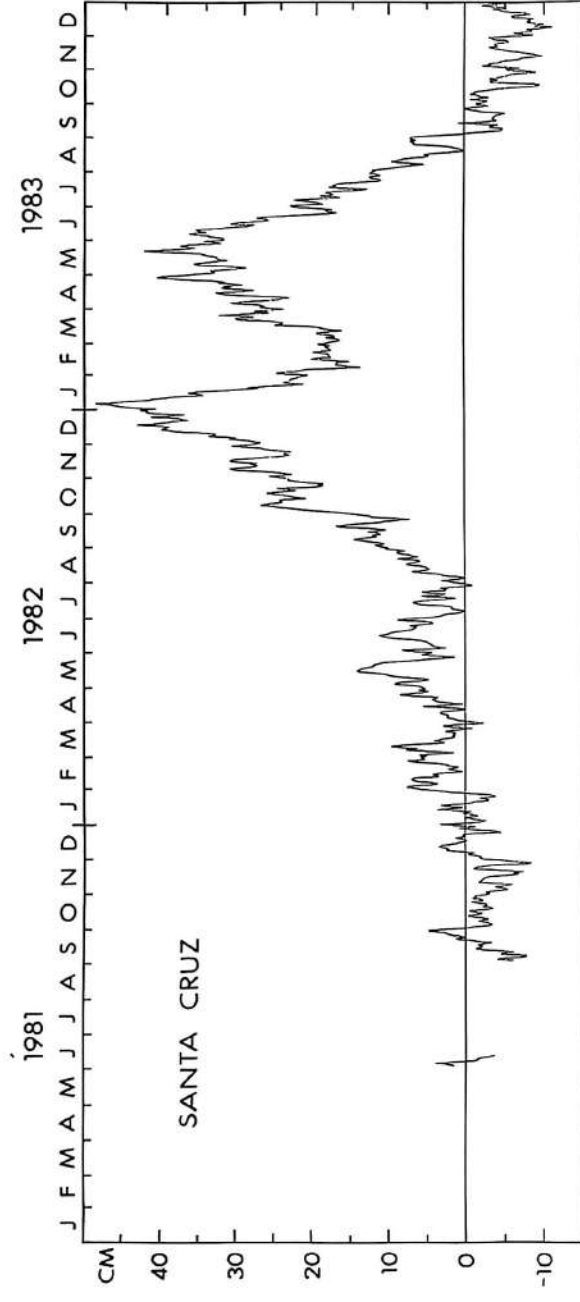


Figure 3. Daily mean sea level at Santa Cruz, from 1981 to 1983 in cm relative to the long term mean.

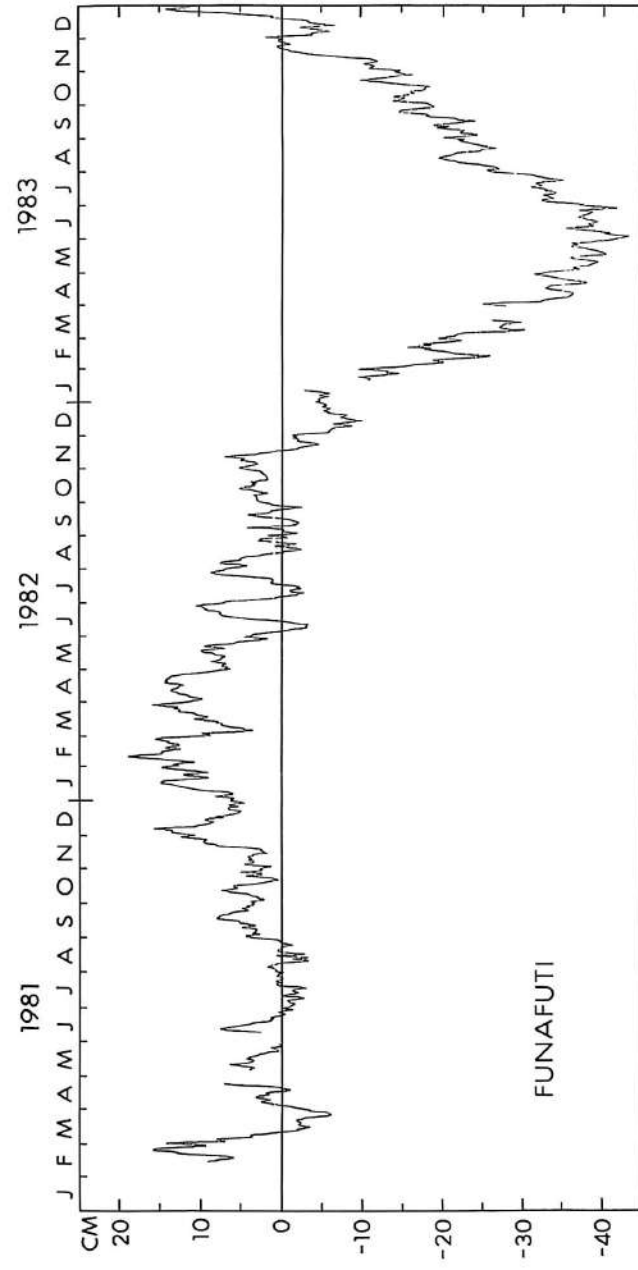


Figure 4. Daily mean sea level at Funafuti, from 1981 to 1983 in cm relative to the long term mean.

consistently appear from January to March 1982. They are opposed by weak negative anomalies in the region of the Easter Island high pressure system.

The positive anomalies indicate a larger heat content of these waters and a depression of the thermocline. In April, May and June sea level along the countercurrent trough near 10°N drops, while it remains normal near the equator. This indicates an intensification of the north Equatorial Countercurrent. Sea level in the area around Samoa and Tahiti remains above normal. This higher than normal sea level in the western Pacific before the onset of the 1982-83 El Niño was much smaller than the build-up observed before previous El Niño events and should not be construed as a cause for the 1982 event. Along the coast of Ecuador and Columbia sea level is about 10 cm above normal in the first half of 1982, while it is about normal along Peru. It seems that the waters in the Gulf of Panama and to the north of the Galápagos Front were either warmer or that the warm layer was thicker before the 1982 El Niño.

The first drastic change in sea level occurs in July 1982 (Fig. 5), when a strong negative anomaly develops along the countercurrent trough and reaches a value of -18 cm at Truk. At the same time a positive anomaly develops along the equator with a maximum value of +17 cm at Christmas Island. The strong westerly winds over the western Pacific to the north of the equator had generated a Kelvin wave that started to travel east. The drastic rise of sea level at Christmas Island on 10 July 1982 indicates the arrival of

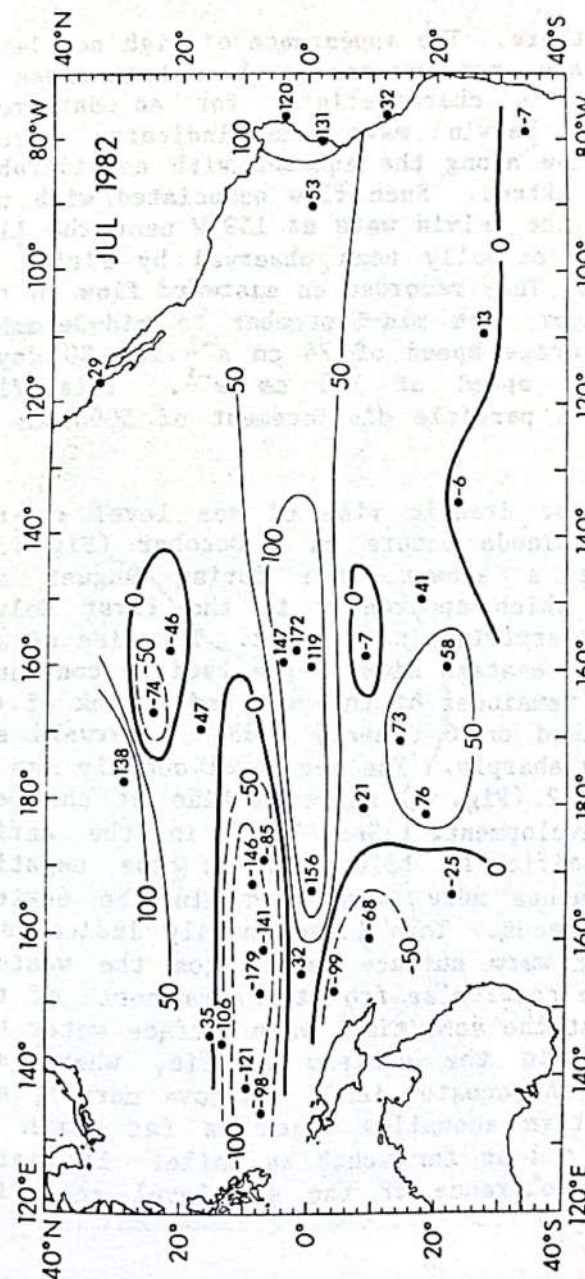


Figure 5. Anomaly of monthly mean sea level in July 1982 in mm.

this wave there. The appearance of high sea level at the equator and low sea level on both sides of the equator is characteristic for an eastward-progressing Kelvin wave and indicates strong eastward flow along the equator with considerable meridional extent. Such flow associated with the passage of the Kelvin wave at 159°W near the Line Islands has actually been observed by Firing et al. (1983). They recorded an eastward flow in the surface layer from mid-September to mid-December with an average speed of 74 cm s^{-1} for 80 days, and a peak speed of 140 cm s^{-1} . This flow represents a particle displacement of 5000 km to the east.

The first drastic rise of sea level at the Galápagos Islands occurs on 3 October (Fig. 3). It follows a slower rise during August and September, which apparently is the first Kelvin wave signal arriving in the east. The rise of sea level at the eastern side of the Pacific continues during the remainder of the year and a peak of +47 cm is reached on 6 January 1983. Afterward sea level drops sharply. The sea level anomaly map of December 1982 (Fig. 6) shows El Niño at the peak of its development. Sea level in the entire western Pacific is below normal; the negative anomaly reaches more than 25 cm in the eastern Caroline Islands. This large anomaly indicates a draining of warm surface water from the western Pacific, in particular from the area north of the equator. At the same time, warm surface water has accumulated in the eastern Pacific, where sea level near the equator is 35 cm above normal, and where positive anomalies reach as far north as California and as far south as Chile. The large horizontal coherence of the sea level anomalies

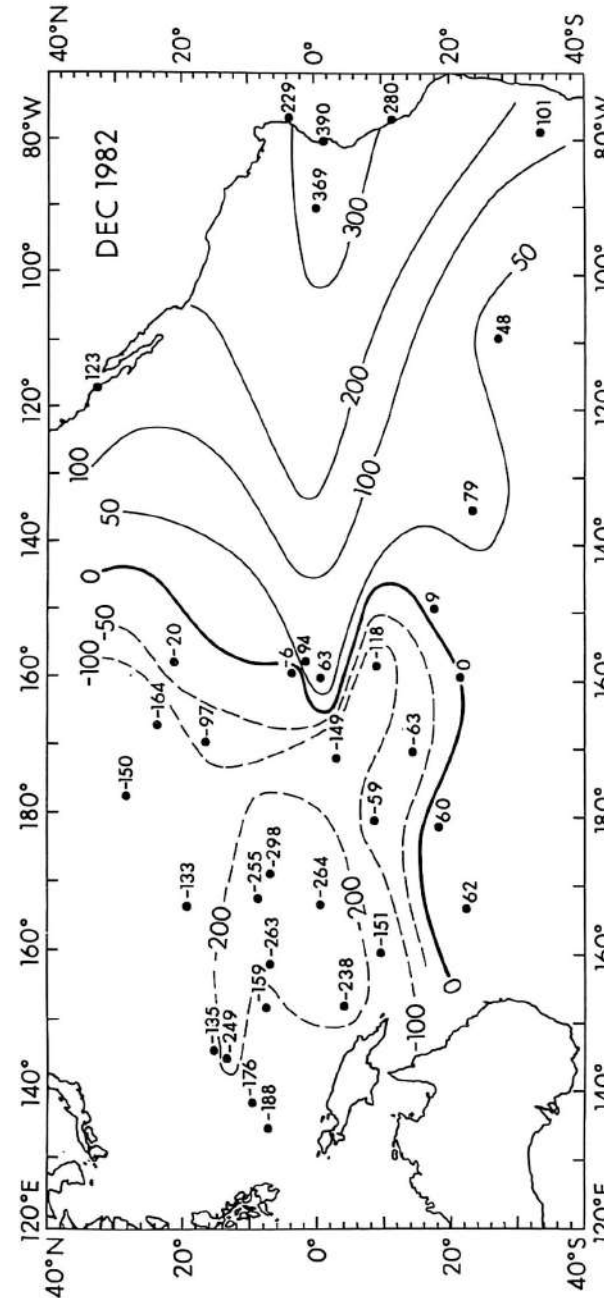


Figure 6. Anomaly of monthly mean sea level in December 1982 in mm.

demonstrates that the entire tropical and subtropical Pacific responds to the changing wind system in a coherent manner, and that the pattern of response is of ocean-wide dimensions.

During the first half of 1983 westerly winds blew over the waters between the Solomon Islands and the Marquesas Islands in opposition to the normal trade winds. The effect of these unusual winds is illustrated by the sea level map of May 1983 (Fig. 7). Over a wide area from the Solomon Islands to Tahiti sea level is depressed; lowest values of -41 cm are seen at Funafuti. At the same time a second peak of sea level is reached at the Galápagos Islands and along the coast of Ecuador and Peru. The deep depression of sea level in the western Pacific also indicates an anomalous circulation. North of the low, between the equator and 10°S, surface flow should be eastward, moving warm water toward the Marquesas Islands. This accumulation of abnormally warm water in the eastern Pacific between the equator and 10°S is obvious in maps of sea surface temperature (Arkin et al., 1983). South of the depression in sea level, between 10° and 20°S, flow is westward, indicating a southward displacement of the South Equatorial Current and apparently of the entire subtropical gyre of the South Pacific (Wyrtki, 1984b).

The recovery of the sea surface topography and of the associated circulation after the 1982-83 El Niño is a slow process. Although the major disturbances in the wind field had disappeared by July 1983, restoration of the normal topography of the sea surface is taking much longer. Sea level

in the area of the Solomon Islands is still 18 cm below normal in October (Fig. 8). This indicates a very slow filling of the depression in sea level seen in the map of May 1983 (Fig. 7). Sea level is also low along the equator from Kapingamarangi to Christmas Island indicating a loss of warm water from the equatorial region as a result of El Niño. In contrast, sea level along the countercurrent trough is high, indicating a very weak counter-current, a situation one would expect at the end of El Niño. At the coast of Ecuador sea level in October is still slightly above normal, whereas it is below normal in the Galápagos Islands.

The main result of this analysis of sea level fluctuations in the Pacific during the 1982-83 El Niño is recognition of the very large, basin-wide coherence of sea level fluctuations and of their long time scales. Sea level is an excellent parameter for monitoring the response of the ocean to a changing wind field and for studying the dynamics of these responses.

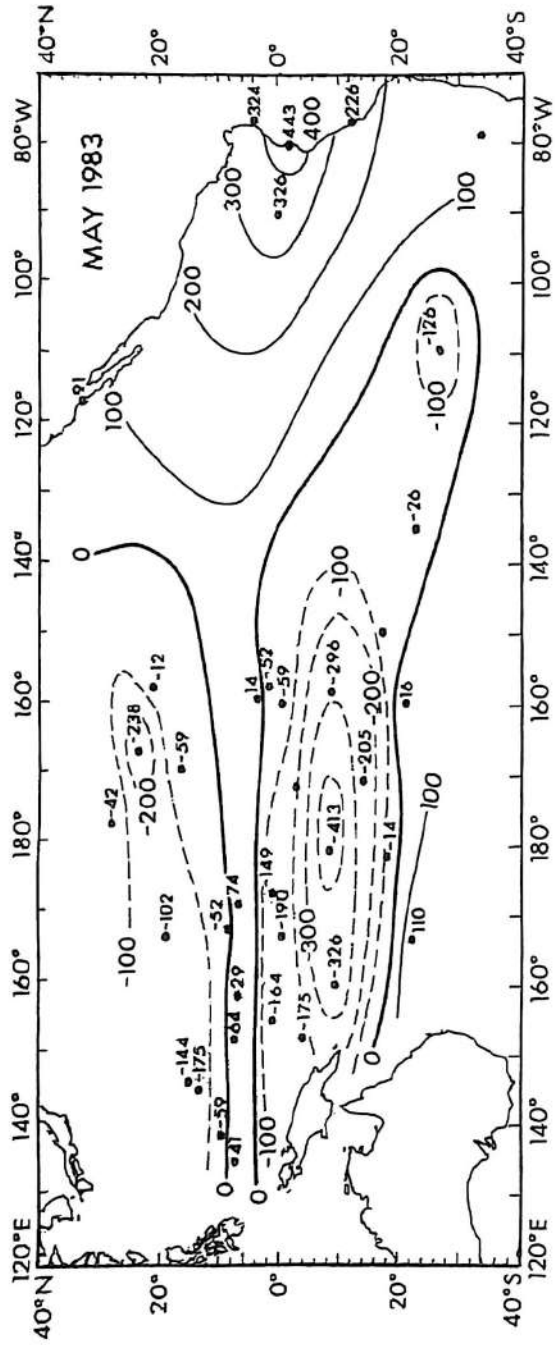


Figure 7. Anomaly of monthly mean sea level in May 1983 in mm.

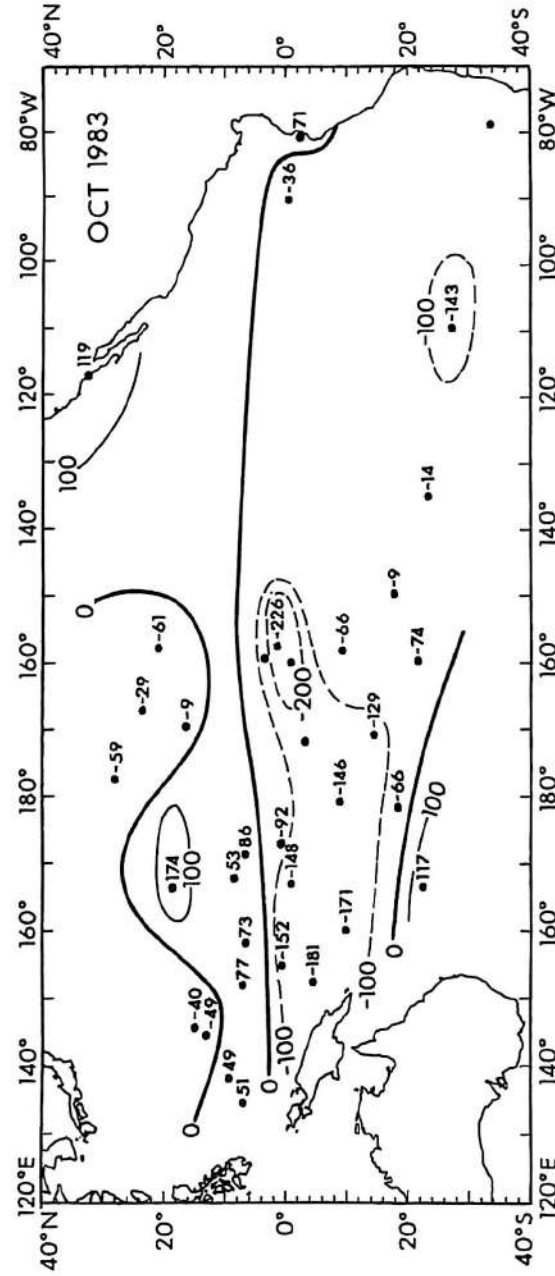


Figure 8. Anomaly of monthly mean sea level in October 1983 in mm.

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SEA LEVEL AND NEAR SURFACE TEMPERATURE VARI-
ABILITY AT THE GALAPAGOS ISLANDS, 1979-83.

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Abstract.

An array of near surface temperature and pres-
sure gauges on the Galápagos Islands was used to
describe changes in the thermal field and sea level
which occurred during the 1982-83 El Niño event.
These changes are contrasted with the variability
observed during the three year period (July 1979 to
July 1982) prior to the event. The location of
gauges on the western side of the archipelago per-
mitted monitoring of the strength of the Galápagos
Front. In non El Niño times the cross front tem-
perature gradient had a strong annual variation; it
was largest in October. A station usually north of
the front had pronounced semiannual variability
while south of the front the annual component was
dominant. The superposition of these two signals
led to the observed annual change in frontal
strength. During the El Niño event the front
disappeared from the islands in October 1982 and
did not reappear until July 1983. During the
redevelopment, cold water occurred first at the
southern stations; its occurrence north of the
front was delayed by about 1 month. By October
1983 the cross frontal temperature gradient in the
islands was near normal.

El Niño related sea level variations at the Galápagos reflected the large scale changes throughout the tropical Pacific. Maxima were observed in December 1982 and May 1983. The onset of rising sea level in early August 1982 followed by about one month the sea level rise in the central Pacific. This initial signal had properties consistent with equatorial Kelvin wave dynamics. The subsequent development was not so easily described.

Resumen

Se utilizó un arreglo de sensores de temperatura y presión cercanos a la superficie en las Islas Galápagos, para describir los cambios de campo térmico y del nivel del mar que ocurrieron durante El Niño 1982-83. Estos cambios fueron comparados con la variabilidad observada en un período de tres años previo al evento (julio de 1979 a julio de 1982). La ubicación de los instrumentos en el lado occidental del archipiélago permitió observar la intensidad del frente de Galápagos. En períodos en los que el fenómeno El Niño estaba ausente, la gradiente de temperatura normal del frente tuvo una fuerte variación anual; su máximo se observa en el mes de octubre. Una estación normalmente ubicada al norte del frente mostró una pronunciada variación semianual, mientras que al sur del frente la componente anual fue dominante. La superposición de estas dos señales produjo el cambio observado en la intensidad del frente. Durante el evento El Niño, el frente desapareció de las islas en octubre de 1982 y no reapareció hasta julio de 1983. Durante su reestablecimiento, agua relativamente fría apareció primero en las estaciones más al sur y un mes más tarde en la estación ubicada al norte del frente. Para octubre de 1983 la gradiente de temperatura normal del frente estaba cerca de su valor normal en las islas.

Las variaciones del nivel del mar en las Galápagos debidas a El Niño fueron un reflejo de los cambios en escalas grandes que ocurrieron en todo el Pacífico tropical. Sus máximos fueron observados en diciembre de 1982 y mayo de 1983. El comienzo del aumento del nivel del mar al principio de agosto de 1982 ocurrió aproximadamente un mes más tarde que la correspondiente elevación de la superficie del mar en el Pacífico central. Esta señal inicial tenía propiedades consistentes con la dinámica de ondas de Kelvin ecuatoriales. Su desarrollo posterior no puede ser descrito en una forma tan sencilla.

Introduction.

The large scale oceanic and atmospheric variability associated with the 1982-83 El Niño event are discussed in Wyrtki (1985). His article sets forth the changing physical environment in which the Galápagos Islands were situated and suggests interpretations of the large scale changes in terms of local and remote wind forcing of the ocean. In this paper we focus on variability at the Galápagos as observed in our array of near surface pressure and temperature gauges. Since our study began in 1979, we have a three year time period before the event (July 1979 to July 1982) to study the normal low frequency variability. This variability is contrasted with changes during the El Niño. Results are used to investigate some of the dynamical inferences based on the large scale analysis and to study some peculiarities of the inter-island differences at the Galápagos.

Much of our knowledge of the low frequency, large scale variability of the tropical Pacific

Ocean has been obtained through analysis of island and coastal sea level records. Non-tidal sea level variations reflect a variety of atmospheric and oceanic changes. In low latitudes, where atmospheric pressure perturbations are small and theoretical considerations suggest that low frequency barotropic (depth independent) oceanic pressure fluctuations are negligible, the dominant cause of non-tidal sea level change is thought to be internal readjustments of the density stratification of the water column. These readjustments could be associated with heating and cooling, precipitation and evaporation, large scale internal wave processes, or geostrophic ocean currents. Any process which replaces dense water with less dense water tends to make sea level rise.

In addition, a dynamic effect on sea level which is often ignored is the pressure perturbation associated with an ocean current flowing around an obstacle. Pressure is higher on the upstream than on the downstream side of the island. This process is potentially important in a swift current such as the Equatorial Undercurrent (EUC) and has been the subject of a recent study at Jarvis Island in the central Pacific (Roemmich, 1984). Results suggest that the strength of the EUC (assuming meanders are not important) can be simply monitored with a pair of pressure gauges spanning the island. While this result is encouraging from the standpoint of monitoring the flow, it reveals a complication in the use of island sea level records as an index of large scale ocean variability. The records may adequately describe the qualitative structure of the large scale changes; but, in regions of locally intense currents, quantitative studies may be severely contaminated.

Sea level variability can be determined either by directly measuring water depth relative to a fixed reference point (e.g., a surface tide gauge) or by measuring pressure fluctuations with a shal-

low, bottom moored pressure gauge. The two measurements will differ because of atmospheric pressure changes and density variations in the water above the gauge. Since pressure change is the parameter of most interest to oceanographers, at mid and high latitudes one generally assumes the "inverse barometer effect" and adds atmospheric pressure to sea level to obtain "synthetic subsurface pressure." As noted above, in tropical regions atmospheric pressure changes are generally small and can be ignored; sea level and subsurface pressure are considered equivalent. One further point to keep in mind is that both direct sea level and near surface pressure measurements only establish the relative change in pressure between two locations. The absolute pressure or height difference cannot be determined without knowing the level of the gauges relative to the geoid.

In order to study the sea level variations near the Galápagos Islands we have maintained an array of near surface pressure and temperature gauges since July 1979. Our specific interests were interpretation of the measurements in terms of (a) low frequency equatorial trapped waves, (b) changes in upper ocean heat content, and (c) fluctuations in the near surface zonal velocity. To investigate these processes gauges were deployed on the western side of the archipelago (figure 1) at Caleta Iguana ($0^{\circ}59'S$, $91^{\circ}30'W$) and Vincente Roca ($0^{\circ}3'S$, $91^{\circ}28'W$) on Isabela Island (referred to as SI and NI, respectively) and at Wenman (Wolf) Island (WI; $1^{\circ}24'N$, $91^{\circ}50'W$). A fourth gauge was added on the eastern side of the islands in November 1980 at Bahia Hobbs (SC; $0^{\circ}42'S$, $89^{\circ}18'W$) on San Cristóbal Island. The mean depth of the instruments are SI: 14 m, NI: 16 m, WI: 25 m, SC: 16 m. These gauges were recovered and deployed annually, normally in November using the M/V BEAGLE III. Technical details of the gauges and the data processing are discussed in

Hayes et al. (1978), Ripa and Hayes (1981) and Hayes and Halpern (1984). In this report pressure changes are referred to in terms of equivalent sea level fluctuations assuming 1 mbar = 1 cm.

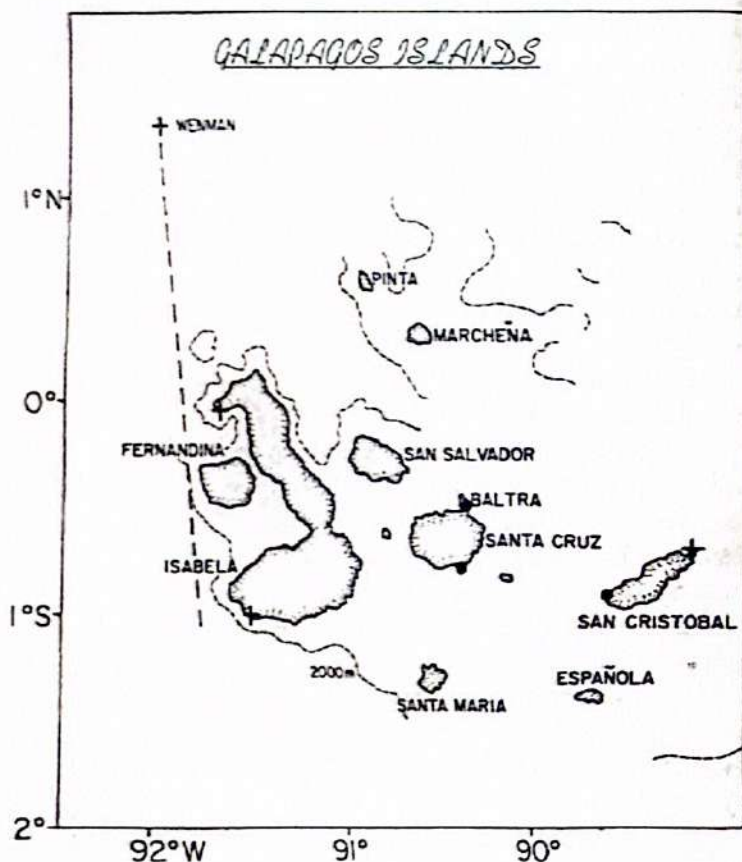


Figure 1. Location of subsurface pressure and temperature gauges (+) in the Galapagos Islands. The location of historical (Baltra and San Cristóbal) and current (Santa Cruz tide gauge measurements) are also shown. The trackline of the XBT section west of the islands is indicated by the dashed line.

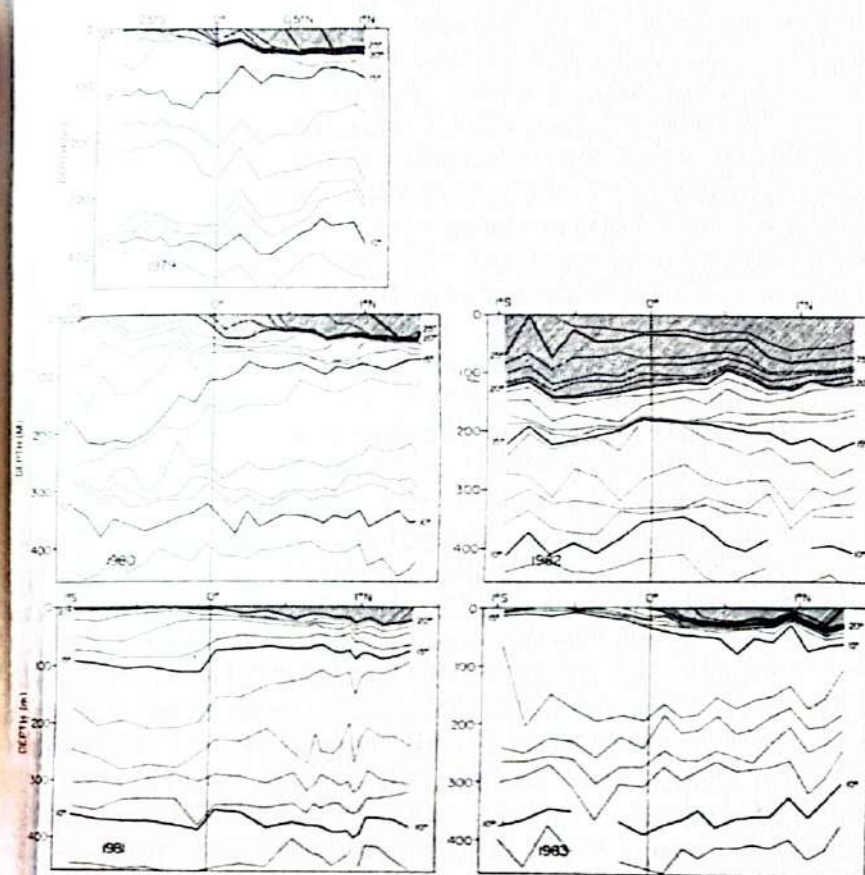


Figure 2. Temperature sections taken in November along the trackline shown in figure 1 for the five years indicated.

Temperature Variations.

On deployment/recovery cruises XBT temperature sections (figure 2) were made along the trackline shown in figure 1 on the western side of the islands from 1°S to 1.5°N. Near surface structure on these sections is dominated by the Galapagos Front. This feature of the large scale oceanic circulation in the eastern Pacific crosses the

equator near the Galápagos and extends southeastward intersecting the South American coast at about 5°S . It separates warm, fresh tropical waters on the north from the cooler, more saline water of the Peru Current. The thermal front varies annually (Wyrtki, 1966). It is strongest from May to November when temperature differences of up to 5°C and salinity changes of up to 1‰ in 50 km are observed. From January to March when the southern waters warm the thermal front disappears; however, the salinity gradient remains. During El Niño events when the northward wind stress relaxes, there is some evidence (Wooster and Guillen, 1974) that the warm fresh water flows southward and the front disappears or moves far to the south.

In our November temperature sections (water warmer than 20°C is cross hatched in figure 2) the Galápagos Front was well developed north of the equator in 1979, 1980, and 1983. Surface temperature changed by about 5°C from 0° to 1.3°N . The mixed layer depth was about 25 m at the northern limit and negligible at the equator. In November 1981 the Front was displaced to the north and cold water extended north of Wenman Island. The greatest change in near surface structure was apparent in November 1982. This section occurred about four months after the initial sea level rise associated with the 1982-83 El Niño (see figure 7). No evidence of the Galápagos Front was seen. Waters warmer than 26°C extended from the north to about $.7^{\circ}\text{S}$ and no surface water cooler than 25°C was observed. The 20°C isotherm which typically is within 25 m of the surface on the equator was 120 m deep. A massive change in upper ocean thermal structure had occurred.

No salinity measurements were made on our BEAGLE III cruises. However, on 7-8 November 1983, about two weeks prior to the XBT section in figure 2 the NOAA Ship RESEARCHER occupied a CTD section from 2°N to $2^{\circ}30'\text{S}$ along $92^{\circ}30'\text{W}$ about

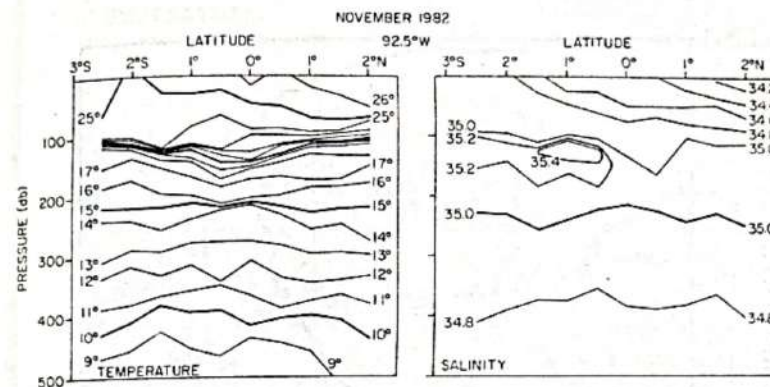


Figure 3. Temperature and salinity distribution along $92^{\circ}30'\text{W}$ in November 1982.

100 km west of the Galápagos. Temperature and salinity distributions on this section are shown in figure 3. We note that although surface temperature was fairly uniform, a strong meridional salinity gradient was still observed. The warm water near the equator does not have the low salinity ($<34\text{‰}$) characteristic of waters north of the Galápagos Front. It thus appears that, initially, the warm waters near the Galápagos in the 1982-83 event were not caused by southward advection of the warm fresh tropical waters of the north. Rather, their characteristics are more nearly associated with waters to the west of the islands. In contrast, figure 4 shows the April 1983 temperature-salinity (T-S) diagram at 0° , $92^{\circ}30'\text{W}$ overlaid on the November 1982 data. In April, surface waters were very warm ($T_0 = 30.4^{\circ}\text{C}$) and fresh ($S = 32.9\text{‰}$). This low salinity water was in a thin ($\sim 15\text{ m}$) mixed layer which ended in a sharp halocline. The temperature quasi-mixed layer was thicker; water warmer than 29°C extended to 40 m. However, with our data we cannot determine whether the low salinity water was the result of locally heavy rainfall or advection from the north.

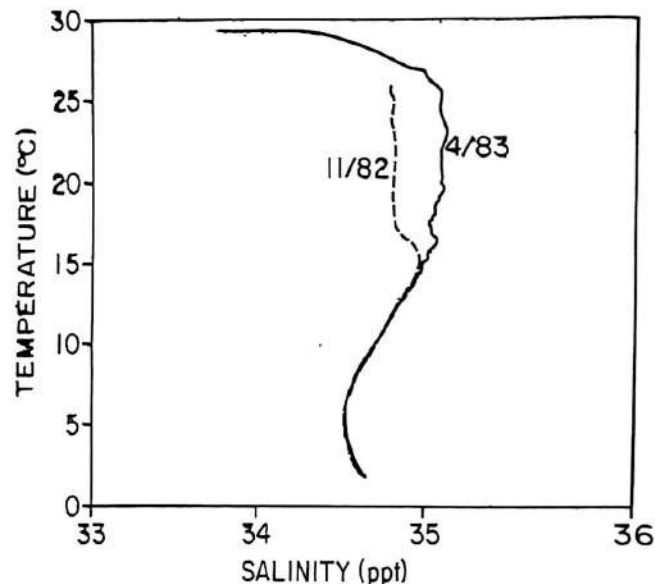


Figure 4. Temperature-salinity diagrams at $0^{\circ} 92^{\circ}30'W$ for November 1982 and April 1983.

The general position of the Galápagos Front just north of the equator west of the islands suggests that our island temperature records, particularly at NI and WI, could provide an effective monitoring of frontal location and strength. Daily average values of temperature at the four gauges are shown in figure 5. Considerable high frequency structure is superimposed on the dominant low frequency variations. The development of the 1982-83 event is seen by the onset of warming in mid-August 1982 and a continually increasing temperature until July 1983. The high frequency variance levels were similar at all gauges. Spectral analysis of the

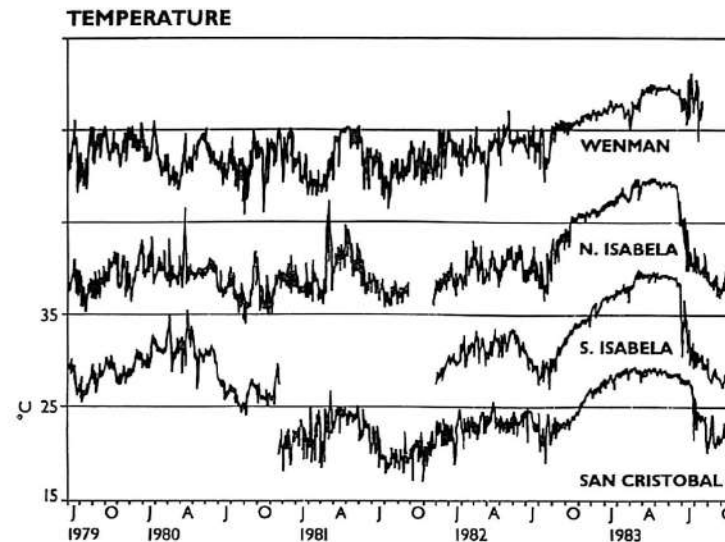


Figure 5. Daily averaged values of temperature at the four sites shown in figure 1 for the period July 1979 to November 1983. The temperature scale for San Cristóbal is indicated, successive plots are offset by $10^{\circ}C$.

records revealed no particular frequencies with statistically significant variance peaks. Rather, the variance density spectra in the period band from 180 to 2 days decreased monotonically from low to high frequency with a shape approximated by frequency to the -1.3 power. During the El Niño event high frequency variance decreased. This result presumably reflects the greater mixed layer depth and lateral homogeneity during the warm episode.

The low frequency variability is more easily discussed in terms of low pass filtered data (figure 6a) with a 30 day half-power point. The occurrence of the Galápagos Front between NI and WI is obvious in this figure. NI and SI lie south of the front and generally track one another. WI

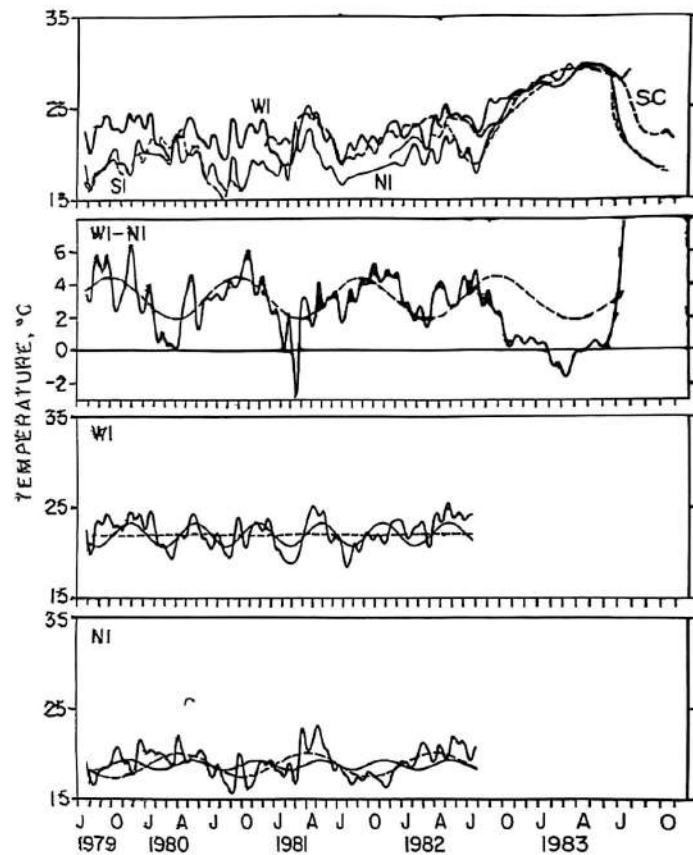


Figure 6. (a) Low pass (30 d half power point) filtered temperature data at all sites. (b) temperature difference between WI and NI, dashed curve indicates annual component fit to data from July 1979 until July 1982. (c) temperature record at WI dash curve is annual component, solid curve is semiannual component fit to non El Niño period. (d) same as (c) for NI.

and SC also follow each other reasonably well and appear to be on the warm side of the front. It is surprising that SC at 0°42'S agrees better with WI (1°24'N) than with the southern stations. Apparently, the front angles sharply across the equator in the Galápagos. This result is qualitatively in agreement with the suggestion that the EUC flows southward around the islands (Stevenson and Taft, 1971; Lukas, 1981). Upwelling associated with this current flowing eastward along upward sloping isopycnals would keep the western side of the Galápagos cool near the equator and could contribute to maintaining cooler water south of the islands.

The annual variation in the strength of the front is apparent in figure 6b where the difference WI-NI is plotted. The gradient weakens or disappears each January to April and is strongest in about October. This cycle was interrupted by the El Niño event which reduced all gradients in November 1982 and the water remained relatively homogeneous until June 1983. The smooth curve on figure 6b is a fit of the three years of data July 1979 to July 1982 to an annual cycle. This fit explains 37% of the variance. The amplitude is 1.3°C and the phase of the maximum relative to 1 January is 274° (i.e., maximum temperature difference in October). This annual amplitude corresponds to a meridional gradient of $8.5 \times 10^{-6} \text{ }^{\circ}\text{C m}^{-1}$.

Close examination of figure 6a shows that the annual cycle in frontal strength does not result solely from a warming in the south. The water at WI north of the front also cools down. The difference between WI and NI temperature records is further exemplified by figures 6c and 6d where these data and the annual and semi-annual components are plotted. These components are again based on the three pre-El Niño years July 1979 - July 1982. At WI the annual component was negligible (explained 0.2% of the variance); however, the

semi-annual component was significant (explained 32% of the variance). The semi-annual amplitude and phase are 1.3°C and 287° (maxima in May and November). At NI only the annual component is significant accounting for 37% of the variance with an amplitude of 1.4°C and a phase of 100° (maximum in March). The semi-annual component only accounted for 7% of the variance. The minimum frontal strength in March corresponds to maximum annual component at NI and a near minimum semi-annual component at WI. Similarly, the maximum frontal strength in October occurs at a time when these two components coincide to yield warmest water at WI and coolest at NI.

The reasons for the differences in thermal variability at the equator and at $1^{\circ}24'\text{N}$ are not known. West of the Galápagos at least two processes (oceanic advection and reduced wind stress) contribute to the warming in March-May. Halpern (1984) has shown that surface currents at 0° , 110°W reverse annually nearly in phase with the warming. The February - May period is associated with eastward flow; the October - November cold period is associated with strong westward flow. Lukas (1981) has suggested that when the eastward current is strong, it flows through the Galápagos Archipelago (rather than to the south) carrying warm relatively salty equatorial waters. This could lead to the initial warming on the equator but a relative cooling at WI, which had been in the warm fresh northern tropical waters. Further developments in the February - May period include reduction in the SE trade winds and a near vanishing of the meridional wind component. These effects would contribute to continued warming on the equator and to the north, essentially removing the forcing mechanism which appears to be responsible for the Galápagos Front. Constructing a plausible scenario for the temperature changes at WI in July through December is somewhat more difficult. The equatorial cooling

is likely a response to the increase in the SE trade winds and the SEC. These winds reestablish the front; however, there is presently insufficient information on the interaction of the winds and the ocean currents to describe in detail which processes lead to the observed thermal time series.

The onset of the warm event is most clearly marked at the equatorial station, NI, where temperatures (figure 5) rose sharply in late August (5°C from August 15 to 25). A similar, essentially simultaneous temperature jump occurred at Wenman Island; however, this change appeared as part of a high frequency fluctuation superimposed on a general warming trend. In fact, at WI this warming extended fairly persistently from August 1981 to July 1983. The El Niño warming was not seen as a unique signal at this northern station. At the other island locations an identifiable temperature peak was observed. It rose gradually from August 1982 until February 1983. It then remained relatively constant until mid June. From June 20 to July 13 temperatures south of the normal position of the Galápagos Front fell 9°C at SI and NI. North of the front, WI and SC remained warm. It was not until one month later that SC temperatures dropped (the WI gauge failed at this time so we must use the SC record as an index of the waters north of the front). During this one month period the surface temperature difference from SI to WI was nearly 10°C (figure 6) which was the most intense cross frontal gradient observed in our 52 month record. The timing of the temperature changes suggests that advection of cool surface waters from the south may be important in the reemergence of the Galápagos Front after the warm event. However, it is not known what limits the northward flow of cold water and produces the strong thermal front observed.

Sea Level Variations.

Sea level fluctuations at each island site are shown in figure 7. Records have been detided using response analysis techniques (Munk and Cartwright, 1966) and low pass filtered using a 30 hour half power point filter. The mean sea level at each gauge has been subtracted. Visually, it is clear that the coherent sea level variations are much larger than the incoherent changes. All records appear similar. There were a series of high sea level events from July 1979 to May 1980, then a relatively quiet period until March 1981. Another sea level rise was seen in April 1982. In the three year pre-El Niño period the three highest sea

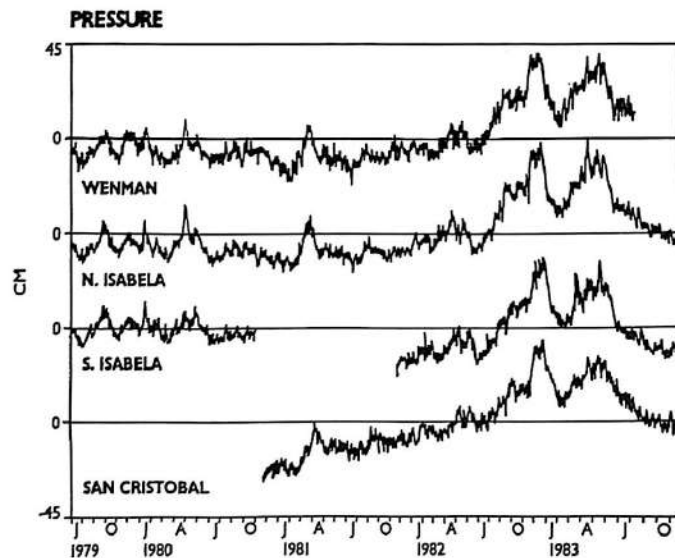


Figure 7. Daily values of pressure at the four sites shown in figure 1. Data have been detided and filtered (30 h half power point). The mean pressure over the time period shown has been removed from each series. Units of pressure are mbar.

levels seen were in May 1980, April 1981, and May 1982. These events amounted to changes in sea level of 15-20 cm. Near the end of July 1982, the first sea level changes clearly related to the warm event occurred; by October sea level had risen 30 cm. It rose another 15 cm in the next two months before falling nearly 30 cm to a relative minimum in February 1983. A second sea level peak extended from March to June. After this, sea level fell at all sites and was near pre-event levels in October 1983.

The frequency composition of the pre-El Niño variability was examined by computing power spectra for the two longest records, NI and WI. These spectra (figure 8) were estimated by averaging Fourier coefficients from the three one year pieces July 1979 to July 1982. The main difference between the two locations occurred near periods of 5 days. WI had a pronounced peak at this frequency while the NI spectrum was featureless. At lower frequencies the two locations were fairly similar. A statistically significant peak occurred at about 12 d periods; below this the variance density increased with decreasing frequency until the semi-annual frequency. The relative drop off in variance density at the annual period indicates that the semiannual component is more important than the annual component at both islands.

To look more closely at the annual (η_a) and semiannual (η_s) variability we fit these constituents to the three years July 1979 to July 1982. The amplitude (in centimeters) and phase of these two signals at NI were $\eta_a = 2.3$, $\phi_a = 124^\circ$ (maximum on 4 May) and $\eta_s = 3.0$, $\phi_s = 251^\circ$. At WI these parameters were $\eta_a = 0.7$, $\phi_a = 121^\circ$ and $\eta_s = 2.9$, $\phi_s = 283^\circ$. The standard errors of the amplitude estimates were all about 1.2 cm. The annual component accounted for about 10% of the low pass filtered (30 d half power point) variance at NI and

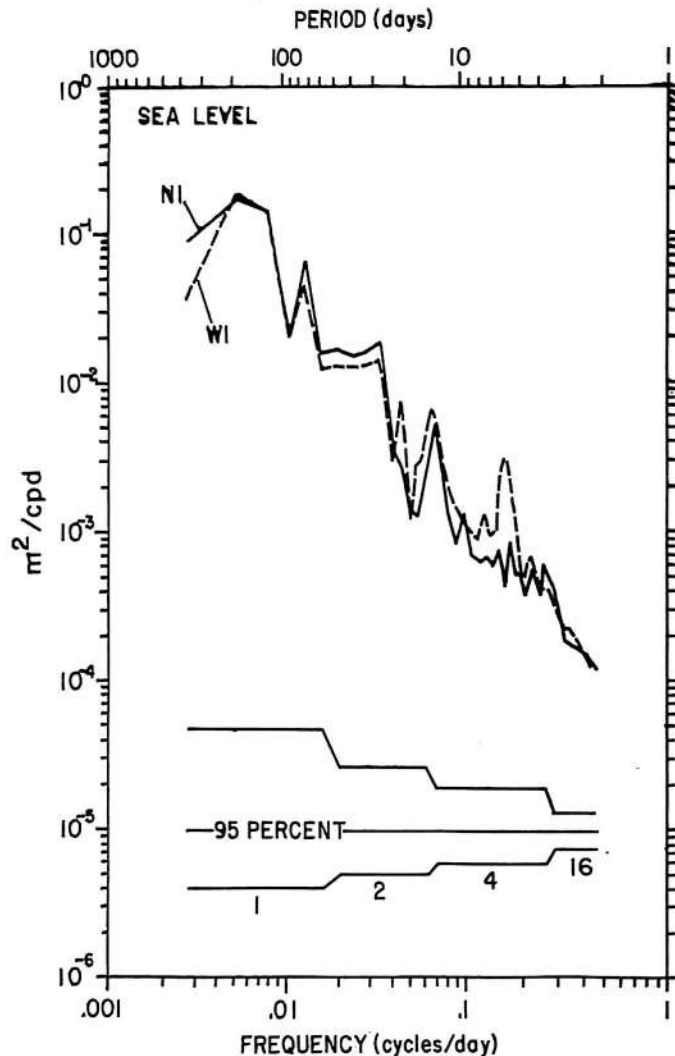


Figure 8. Power spectra of pressure variations from July 1979 to July 1982 at NI and WI.

less than 3% at WI. On the other hand, the semi-annual component accounted for about 18% of the low

pass filtered variance at both locations. These results for the three years studied here contrast with the longer historical records at Baltra (1968-77) and San Cristóbal (1959-68) (see figure 1) which Wyrтки and Leslie (1980) analyzed. They found annual (semiannual) components at Baltra of $\eta_a = 3.0$, $\phi_a = 84^\circ$ ($\eta_s = 1.2$, $\phi_s = 101^\circ$) and at San Cristobal of $\eta_a = 2.4$, $\phi_a = 93^\circ$ ($\eta_s = 1.2$, $\phi_s = 7^\circ$). As indicated by the relatively large standard errors of the regression coefficients, our records are too short to quantitatively study variations in the annual and interannual sea level components among the islands. Nevertheless all analyses indicate that these components are small compared to the event-like signals seen in boreal spring or to the El Niño sea level rise.

As noted in figure 7, the low frequency changes at all the islands were highly correlated. Comparison with Wyrтки (1984) indicates that our pressure records were also well correlated with the tide gauge at Academy Bay on Santa Cruz Island. The relation of these data to the large scale sea level changes are discussed in Wyrтки (1985) and a discussion of events which appear to propagate between the central and eastern Pacific is presented in Lukas et al. (1984). The latter paper finds evidence for equatorial waves in the cross correlation functions between Galápagos Island and Jarvis Island ($0^\circ 23'S$, $160^\circ W$) or Christmas Island ($2^\circ N$, $157^\circ W$) sea level. Correlation peaks were found with lags corresponding to eastward propagation of first and second vertical mode Kelvin waves and westward propagation of first vertical, first meridional mode Rossby waves. In figure 9, NI and Jarvis sea level are over plotted with the Jarvis record delayed to 30 d which corresponds to a phase speed of $c = 2.9$ m/s which is approximately the speed of a first vertical mode equatorial Kelvin wave. With this time shift many of the peaks in

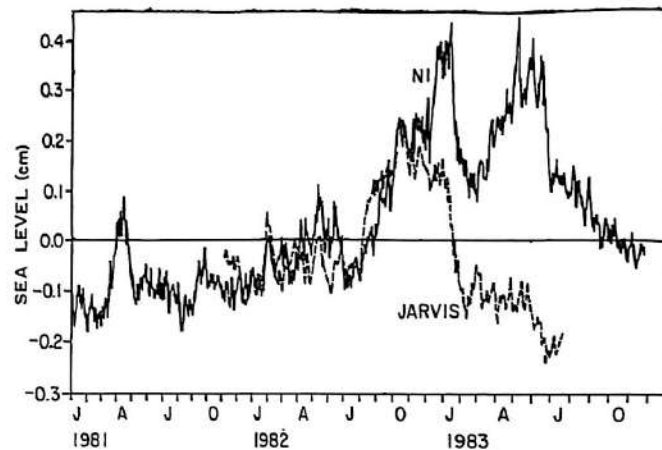


Figure 9. Galápagos sea level (NI) and Jarvis Island sea level delayed by 30 d.

the two records line up. In particular, events in February and May 1982 at the Galápagos are clearly seen 30 d earlier at Jarvis. The early August 1982 sea level rise at NI also corresponds to a dramatic rise at Jarvis which began in early July; however, the rise time in the central Pacific was much shorter. Lukas et al. (1984) attribute this difference to modal dispersion. If the sea level signal is composed of equatorial Kelvin waves with different vertical structures, then each mode will propagate eastward with its respective phase speed. The higher modes travel slower and could lead to the change in shape observed. Lukas et al. (1984) show that the measured rise time of NI could be reproduced by assuming that the Jarvis record consisted of equal parts mode 1 ($c = 2.8$ m/s) and mode 2 ($c \approx 1.3$ m/s).

Following the initial sea level rise, the amplitudes of the time adjusted sea levels at Galá-

pagos and Jarvis agreed in about October 1982. Jarvis sea level then began to drop while Galápagos sea level continued to rise. By December the Galápagos change was 25 cm above the Jarvis change. The difference between these two signals increased in 1983 since the second sea level peak at NI was not present at Jarvis. Sea levels, adjusted to agree before and at the onset of the event, disagreed by nearly 50 cm in April 1983. Since the mean sea level increase from Galápagos to Jarvis is only about 35 cm (relative to 1000 db), the sea level slope was likely reversed during this period (Firing et al., 1983). The structure of the sea level records after November 1982 suggest that local wind forcing may be quite important in determining the Galápagos sea level at this time. Indeed, Arkin et al., (1983) show that in early 1983 the zonal wind anomaly had extended quite far into the eastern Pacific and remained significant until at least June 1983. A simple description of the sea level changes in terms of free waves propagating along the equator as discussed in Lukas et al. (1984) only appears valid at the start of the event.

Hayes and Halpern (1984) showed that during the period March 1980 to July 1981 sea level at the Galápagos was highly correlated with currents measured 2000 km to the west near 0° , 110°W . Because of the lag between current and sea level (10.5 d) and their relative amplitudes, this correlation was interpreted as further evidence for first vertical mode Kelvin waves. Given the similar interpretation for the onset of El Niño conditions, it is of interest to compare these variables during this event. Figure 10 shows low pass filtered (30 d half power point) sea level at NI and zonal current and temperature at 100 m depth near 0° , 108°W (Halpern, personal communication, 1983). The latter two variables have been delayed by 10.5 d. In March through June sea level,

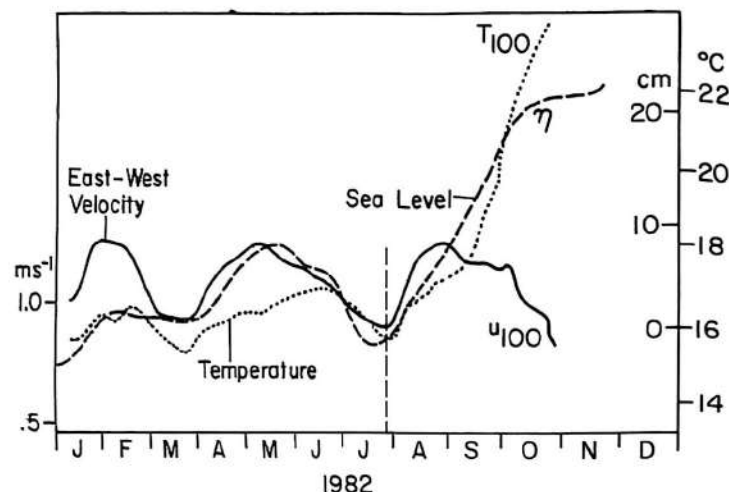


Figure 10. Low pass filtered (30 d half power point) sea level at NI and zonal current and temperature at 100 m depth near 0° , 108°W (Halpern, personal communication, 1983). The 108°W data have been delayed by 10.5 d.

current, and temperature all increased together. The current and sea level changes are consistent with the first vertical mode Kelvin wave interpretation. These records continued to track each other through August 1982 (about one month after the event onset). However, subsequently sea level and temperature continued to increase while zonal velocity decreased. Thus, the simple single vertical mode Kelvin wave model only works reasonably well during the first month after onset. This result is consistent with other observations (Lukas *et al.*, 1984) and model studies (Busalacchi and Cane, 1984) which suggest that other waves become important at about this time. In addition, part of the change in current at 100 m is due to vertical movements of the EUC. Toole and Borges (1984) found that by October the mixed layer at 0° , 110°W

had deepened to nearly 100 m. This depth is below the mean position of EUC core (75 m; Halpern, 1984). In November, Hayes and Mangum (1983) found that the EUC core was at 120 m depth. These large changes in the background stratification and currents make interpretation of the last few months of figure 10 difficult.

Comparison of the Galápagos sea level and temperature records through the event shows an interesting feature. The near surface temperature remained relatively constant in January - February 1983 when the sea level dropped nearly 30 cm. As noted in the introduction sea level is a measure of the heat content of the water column (ignoring salinity effects on density). Thus, although surface temperature remained warm, the internal thermal structure must have readjusted to cause a reduction of heat content during this period. Comparison with upper ocean moored temperature measurements at 0° , 95°W (Halpern, 1984) show that this is, indeed, the case. The 15°C isotherm was at its deepest level (greater than 200 m) in December 1982. Water warmer than 25°C extended to 100 m and surface temperatures were 26° to 27°C . In March 1983 the 15°C isotherm rose to about 150 m and the 25°C isotherm was at 50 m. However, surface warming, confined to a thin layer above a near surface thermocline, continued and surface temperature was greater than 29°C . The estimated heat content in the upper 200 m reflected the change in depth of the 25°C to 15°C isotherms. Maximum heat content occurred in December 1982 and it fell rapidly in early 1983. Qualitatively sea level and upper ocean heat content appear reasonably well correlated throughout the event.

The above discussion has focussed on the large scale changes which are coherent throughout the Galápagos Islands, we now turn to details of the pressure distribution around the islands. Ripa and Hayes (1981) used principal component analysis

(empirical orthogonal functions) to study the correlated sea level fluctuations of the three gauges on the western side of the islands for the first five months of data (July to November, 1979). They interpreted the results in terms of equatorial waves. The first principal component explained 95% of the variance and had a meridional shape consistent with a first vertical mode equatorial Kelvin wave. A similar analysis was done for the period from 1 January 1982 through 22 July 1983 which includes the warm event. Low pass filtered (30 d half power point) data at the three western gauges were highly correlated during this period (all linear correlation coefficients exceeded 0.98). The first principal component explained 99% of the variance and had amplitudes (in cm) at the three locations of WI: 13.7, NI: 14.2, and SI: 12.8. The time series of this component looked quite similar to the NI sea level record. Fitting the meridional shape to a Gaussian in latitude, and assuming that the sea level response is due solely to a single vertical mode Kelvin wave gives an estimate of the wave phase speed as 7.5 m s^{-1} . This speed is about a factor of three greater than the gravest mode Kelvin wave; higher modes have even smaller speeds. Therefore, the average pressure distribution across the islands is not well represented by a single Kelvin wave mode although for some pieces of the data this simple description still holds.

Recent studies (Eriksen, 1982; Hayes, 1982; Lukas and Firing, 1984) have pointed out the utility of the geostrophic approximation even at the equator. The geostrophic component of the zonal current u is given by

$$fu = \beta y u = - \frac{1}{\rho} \frac{\partial p}{\partial y} \quad (1)$$

where $f = \beta y$ is the Coriolis parameter, y is the north-south coordinate, ρ is the water density, and

p is the pressure perturbation. At the equator ($y = 0$) this expression becomes indeterminate if $\partial p / \partial y = 0$. Then the derivative of (1) provides an estimate of current:

$$\beta u = - \frac{1}{\rho} \frac{\partial^2 p}{\partial y^2} \quad (2)$$

This approximation is discussed in the above references; both Hayes (1982) and Lukas and Firing (1984) had reasonable success in estimating the zonal velocity at the equator using equation 2. Poorest agreement was near the surface where current variability is large and ageostrophic terms are likely to be important.

In spite of the possibility of additional terms in the near surface momentum balance, the three western pressure gauges were used to estimate the time variability of the meridional pressure gradient and the geostrophic current at approximately 15 m depth. With only three measurements a finite difference estimate of $\partial^2 p / \partial y^2$ can be obtained or equivalently the equatorial velocity can be estimated as the average of the velocity north and south of the equator. Computations were on daily values of the 30 d low pass filtered data. Two estimates of zonal velocity are shown in figure 11. The first estimate was obtained from equation 1 using the pressure gradient fluctuations north of the equator between WI and NI. The second estimate used equation 2; finite difference estimates of $\partial^2 p / \partial y^2$ were computed at each time step. These velocity estimates are compared in figure 11 with the measured zonal velocity at 15 m at 0° , 95°W (Halpern, personal communication, 1984). The two pressure gradient estimates appear fairly similar. These estimates show some of the general low frequency pattern of the measured velocity. For example, in February through May 1982 and 1983 both estimated and measured velocity were eastward; in June to September they were

westward. The overall correlation coefficients of the estimated and measured velocity were $r_1 = 0.5$ for the first estimate and $r_2 = 0.3$ for the second.

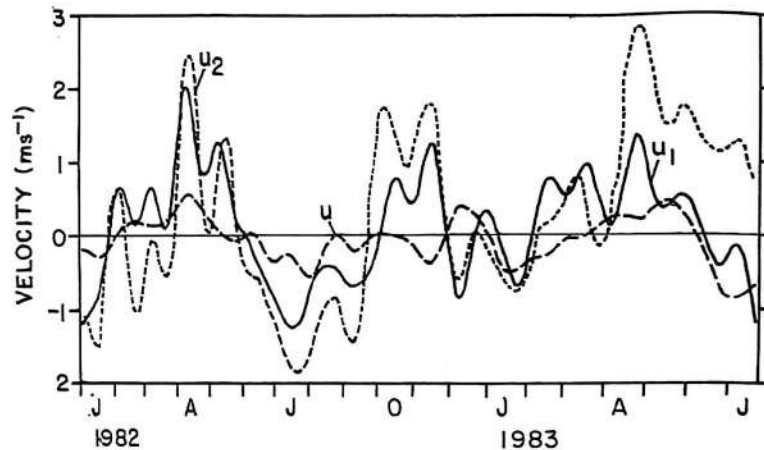


Figure 11. Low pass filtered (30 d half power point) measured zonal velocity (u) at 0° , 95°W (Halpern, personal communication, 1984) and geostrophically estimated velocities using equation 1 (u_1) or equation 2 (u_2) as discussed in the text.

The major discrepancies between computed and measured velocity were the amplitude of the fluctuations and the structure in October - November 1982. Fluctuations of the computed currents were on average a factor of two greater than those in the measured currents. This result implies that equatorial (NI) sea level changes were too large relative to the off equatorial changes. It should be recognized that the sea level differences involved are very small. A 1 cm change in sea level between $\pm 1^\circ$ and the equator corresponds to a geostrophic velocity of about 70 cm s^{-1} . Given the uncertainties, the remarkable result is that low frequency pressure gradient variations actually

were correlated with measured zonal velocity. Many reasons for deviations are possible. These reasons include the pressure field distortions associated with flow around the islands.

Roemmich (1984) reviewed the theory of pressure perturbations caused by high Reynold's number flow around small cylindrical islands. In a uniform, steady flow with speed u_0 the pressure difference between the upstream and downstream side of the island can be written as:

$$\frac{\Delta p}{\rho} = 0.5 (1+\gamma) u_0^2 \quad (3)$$

The form of this expression was chosen to facilitate comparison with laboratory experiments where γ is referred to as the base pressure coefficient. On the upstream side of the island, pressure is elevated relative to its free stream value by $0.5 u_0^2$ and on the downstream side it is reduced by $0.5 \gamma u_0^2$. Roemmich found that for Jarvis Island $\gamma = 0.3$ produced a best fit with his velocity data; laboratory studies (Roshko, 1961) yield $\gamma = .85$. The Galápagos Islands do not satisfy the scaling criteria appropriate for this theory. They are sufficiently large that assumptions of uniform flow and small perturbations by the islands are unlikely to be valid. Nevertheless, it is of interest to examine pressure deviations across the archipelago and attempt correlation with u^2 in order to estimate the importance of this effect.

The low pass filtered pressure difference between SI (1°S) on the western side of the islands and SC ($0^\circ 42'\text{S}$) on the eastern side is shown in figure 12 for the 18 month period January 1982 to July 1983. The time averaged pressure difference between the two sites has been subtracted. This pressure difference time series has considerable low frequency structure. Positive deviations ($\sim 0.03 \text{ dbar}$) occurred in November - December 1982

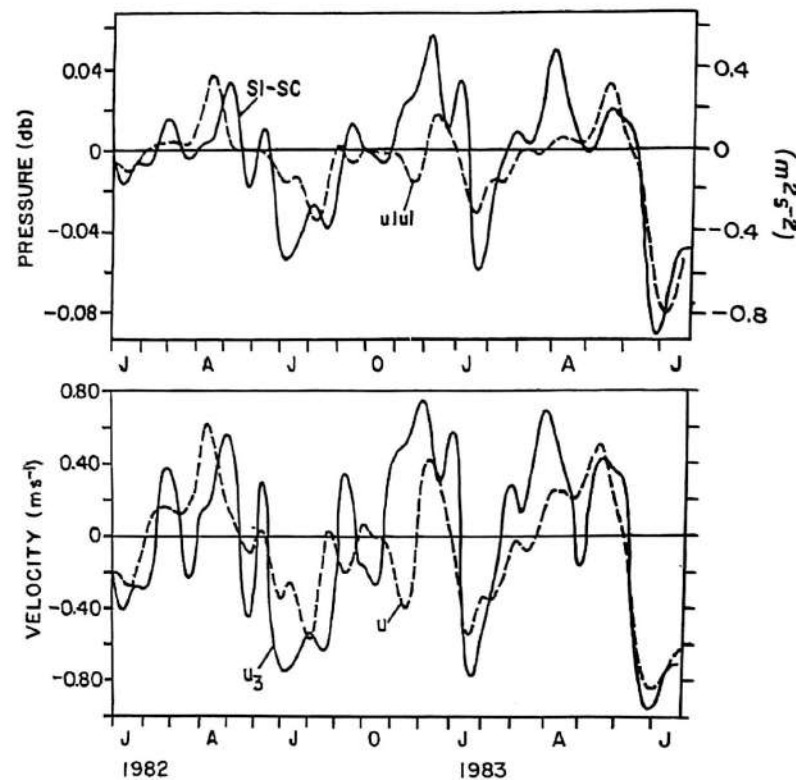


Figure 12. Low pass filtered (30 d half power point) pressure difference between SI and SC and the zonal velocity function $u|u|$ computed from measurements at $0^\circ, 95^\circ\text{W}$ (Halpern, personal communication 1984). The lower frame shows measured (u) and estimated (u_3) zonal velocity using equation 3 with $\gamma = 1.0$.

and negative deviations were found in June to August 1982. For comparison the zonal velocity function $u|u|$ measured at $0^\circ, 95^\circ\text{W}$ is also shown in figure 12. Although this velocity measurement was about 400 km west of the islands, correlation between $u|u|$ and Δp is visually clear. The linear

correlation coefficient between these series was $r = 0.71$ (about 50% of the variance explained). Based on the integral time scale of these series there were about 25 degrees of freedom in this correlation. Thus, r is significant at the 99% confidence level. The regression coefficient between $\Delta p/\rho$ and $u|u|$ was 1.0. Comparison with equation 3 yields $\gamma = 1.0$. That this value is close to the laboratory values is probably accidental considering the uncertainties in our estimation of the flow field and the likely errors in applying potential flow theory. Zonal velocity (u_3) estimated from equation 3 with $\gamma = 1.0$ is compared with the measured equatorial velocity in the bottom panel of figure 12. The correlation coefficient of these two series is $r = 0.67$ and the general trends of the measured velocity are fairly well estimated although the computed velocity has more high frequency structure.

Given the significant correlation between cross island pressure difference and zonal velocity, the question arises as to how significant this island drag effect is on our interpretation of low frequency sea level. As noted above, Ripa and Hayes (1981) interpreted the meridional shape of the sea level fluctuations on the western side of the islands as an equatorial Kelvin wave. The amplitude of this signal was about 0.04 m which in a first vertical mode Kelvin wave implies a surface zonal velocity signal of $g\eta/c = .17 \text{ m s}^{-1}$ (assuming $c = 2.3 \text{ m s}^{-1}$). Such a zonal velocity causes an upstream sea level elevation of only 0.003 m; i.e. about 10% of the Kelvin wave amplitude. Thus, the island pressure effect is not a serious contamination. A similar result holds for the velocity-sea level correlations discussed in Hayes and Halpern (1984). In general, since the sea level elevation in a Kelvin wave depends on u and the island pressure perturbation depends on u^2 , the latter will dominate at high velocities. For the first

vertical mode these two effects yield equal sea level perturbations at an unreasonably high velocity of 4.6 m s^{-1} (again ignoring mean flows). Therefore, the island pressure deviation is likely to be unimportant in many applications; nevertheless, this term cannot always be ignored in quantitative comparisons. Roemmich (1984) has pointed out the potentially important effects which the nonlinearity of this term contribute to high frequency fluctuations.

Acknowledgments

Discussions with P. Ripa and D. Roemmich were helpful in the analysis discussed here. The moored current meter data used in sea level comparisons were graciously provided by D. Halpern. Our Galápagos measurements would not have been possible without the help of many friends on the islands. In particular the skill and dedication of the Captain and crew of the M/V BEAGLE III contributed greatly to our research. We also appreciate the cooperation of the Director and staff of the Charles Darwin Research Station. The continued interest of the Director and staff of the Instituto Oceanográfico de la Armada (INOCAR) del Ecuador has contributed to our measurement program and is gratefully acknowledged. This research was supported in part by the Equatorial Pacific Ocean Climate Studies (EPOCS) Program of ERL-NOAA.

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REGISTROS METEOROLOGICOS DE LA ESTACION
CIENTIFICA CHARLES DARWIN PARA 1982-1983

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Resumen

En octubre de 1982 las características propias del fenómeno El Niño se presentaron, notándose cambios en el clima de Galápagos. Se incrementaron notablemente las precipitaciones y se elevó la temperatura del aire y del mar más allá de lo habitual. Estas condiciones desaparecieron a partir de Agosto de 1983 de manera rápida. Los registros meteorológicos de temperatura del aire, temperatura del mar y precipitación para 1982 y 1983 en Galápagos se comparan con el promedio de los años 1979 a 1981.

Summary

In October 1982, El Niño conditions appeared in the Galápagos Islands. There was a considerable increase in rainfall, air temperature, and sea surface temperature. These conditions ceased abruptly in August 1983. Meteorological records of air and ocean temperatures and rainfall for the years 1982 and 1983 are plotted and compared with mean values for the years 1979 to 1981.

Las lluvias fuertes de octubre de 1982 y las altas temperaturas del aire y del mar indicaron que

un cambio importante se acercaba. En diciembre, las temperaturas del aire y del mar se elevaron y se desencadenaron abundantes lluvias. A finales de diciembre de 1982 y a comienzos de enero de 1983 las marejadas llegaron a Galápagos y se produjeron aguajes fuertes. A partir de Agosto de 1983 cesaron rápidamente las condiciones del Niño.

Los registros meteorológicos para los años 1982 y 1983 se han graficado. Como comparación se ha graficado también el promedio para los años 1979 a 1981 (Herrera 1979, 1980 y 1981). Las figuras que se presentan a continuación muestran la temperatura máxima y mínima del aire (Figura 1), la temperatura del mar (Figura 2) y las precipitaciones y días con lluvia (Figura 3) para la estación meteorológica de la Estación Científica Charles Darwin (ECCD) localizada en Bahía Academia, Isla Santa Cruz, Galápagos. Para esa misma localidad los registros extremos de la temperatura del aire y del mar se dan en la tabla 1. Esta tabla y las figuras 1 y 2 muestran el notable incremento en la temperatura tanto del aire como del mar que se experimentó durante el período afectado por El Niño.

Las tablas 2, 3 y 4 muestran los registros totales de lluvia en varios sitios del Archipiélago. Se nota que durante los años 1982 y 1983 llovió más. Además hubo un número mayor de días con lluvia (tabla 2 y Fig. 3). La figura 4 y las tablas 3 y 4 muestran que las precipitaciones se incrementaron tanto en las partes bajas como en las partes altas de las islas.

Estos cambios en el clima produjeron cambios en la flora y fauna locales, los que se describen en otros trabajos de este volumen.

Registros Meteorológicos de la Estación 85

Tabla 1. Registros meteorológicos extremos de la temperatura en la Estación Científica Charles Darwin, Bahía Academia, Isla Santa Cruz.

	Registro de temperatura (°C)		
	1982	1983	1979-81 (promedio)
A. Temperatura del aire			
Máxima	32.5 (4 marzo)	33.8 (13 febrero y 4 abril)	25.9
Mínima	19.4 (24 octubre)	17.1 (14 diciembre)	21.1
B. Temperatura del mar*			
Máxima	27.5 (24 diciembre)	29.4 (21 y 22 marzo)	23.4
Mínima	21.7 (21 agosto)	21.2 (11 septiembre)	

* Temperatura del mar a las 0700 horas a un pie de profundidad.

Tabla 2. Total anual de lluvia en la Estación Científica Charles Darwin, Bahía Academia, Isla Santa Cruz (2 m sobre el nivel del mar).

Año	Máxima lluvia en 24 horas (mm)	Número de días con lluvia	Total de lluvia (mm)
1982	137.6 (17 diciembre)	106	639.3
1983	122.9 (9 enero)	201	2768.7
1979-81 (promedio)	22.1	53	265.1

Tabla 3. Total anual de lluvia (mm) en dos localidades de la Isla Isabela.

Año	Santo Tomas ¹	Puerto Villamil ²
1982	1506.4	438.9
1983	4100.2	2242.4
1979-81 (promedio)	786.3	148.0

¹ Santo Tomas está a 350 m de altura. Para 1983 no se tuvo registros en mayo y en diciembre.

² Puerto Villamil está a 6 m de altura. Los valores para 1983 corresponden al período enero-agosto. Los datos para Isabela fueron recogidos por la Representación de la ECCC en esa isla.

Tabla 4. Total anual de lluvia (mm) en dos localidades de la Isla San Cristóbal.

Año	El Progreso ¹	Puerto Baquerizo Moreno ²
1980	774.0	190.5
1982	1851.1	365.7
1983	3975.9	3408.8

¹ El Progreso está a 250 m de altura. Los valores de 1983 excluyen a los meses de julio, agosto, noviembre y diciembre.

² Puerto Baquerizo Moreno está a 6 m de altura. Los valores para 1983 excluyen a los meses de septiembre a diciembre. Los datos para San Cristóbal fueron colectados por la Representación de la ECCC en esa isla.

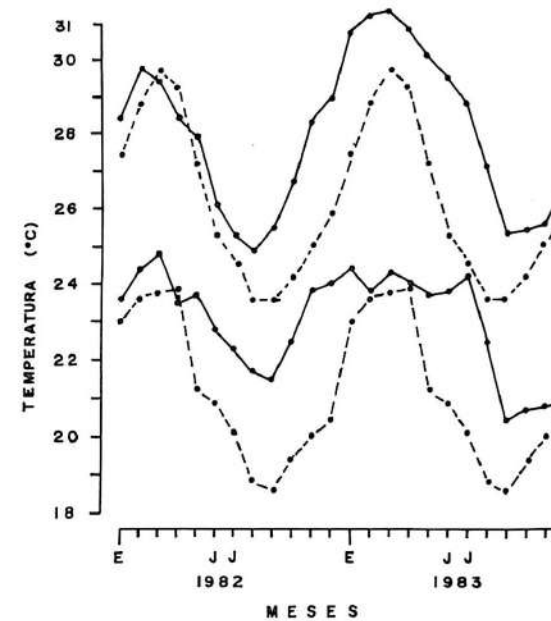


Figura 1. La temperatura (máxima y mínima) del aire registrada en la Estación Darwin en la Isla Santa Cruz. Las líneas cortadas representan los promedios para 1979-1981.

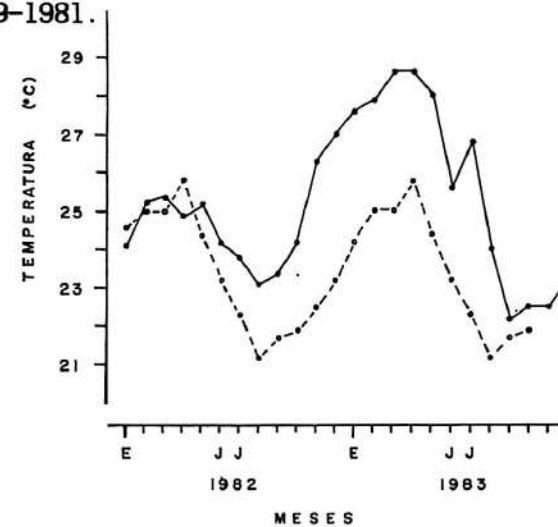


Figura 2. Promedios mensuales de la temperatura del mar en la Bahía Academia, Isla Santa Cruz. La línea cortada representa los promedios para 1979-1981.

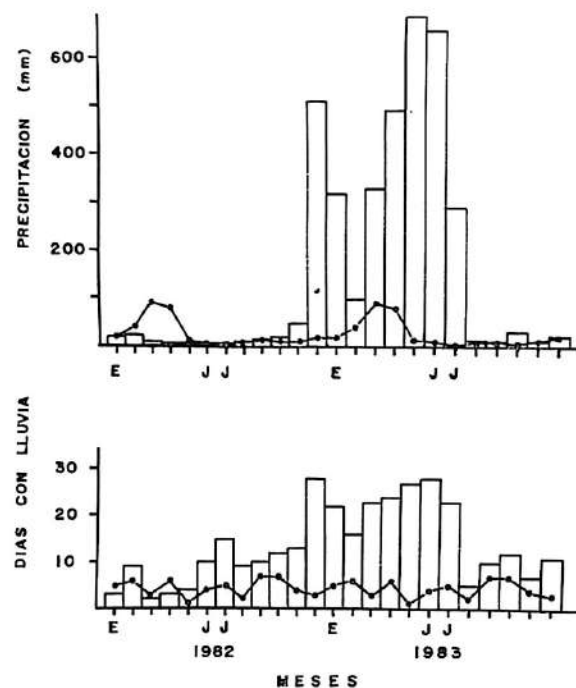


Figura 3. Histogramas de la precipitación y días con lluvia registradas en la Estación Darwin en la Isla Santa Cruz. Las curvas son los promedios para 1979-81.

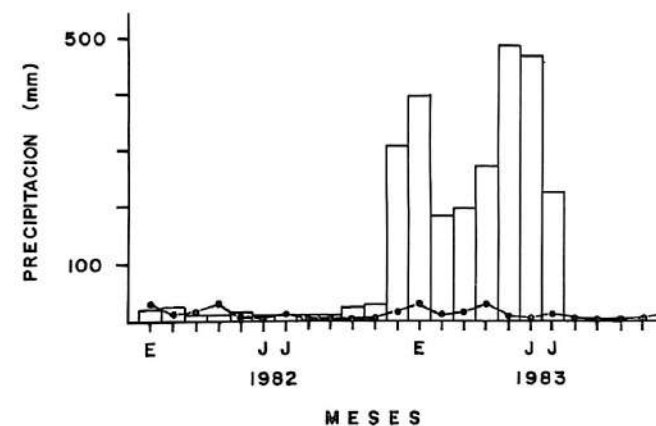
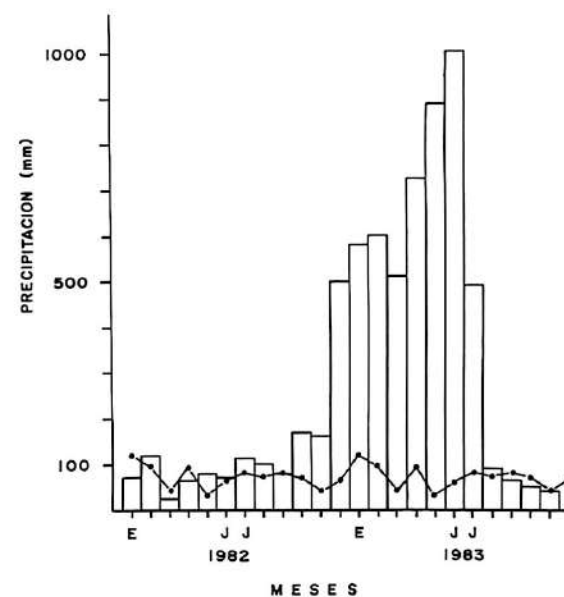


Figura 4. Precipitación en Santo Tomás (arriba) y Puerto Villamil (abajo) en la Isla Isabela. Las curvas representan los promedios para 1979-81.

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OCEANOGRAPHIC CONDITIONS IN THE GALAPAGOS

ISLANDS DURING THE 1982/1983 EL NIÑO

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Summary

Temperature, salinity, nutrient and chlorophyll measurements from a time series station located on the 100 m contour in Academy Bay, Isla Santa Cruz defined oceanographic conditions during the 1982/83 El Niño. Discrete samples were collected from 0, 10, 25 and 60 m three times a week from June 1982 to December 1983 to determine the oceanographic changes. Conditions started to change in late November 1982. Temperatures climbed to over 26°C, nitrate, phosphate and silicate decreased and the salinity dropped below 34‰. This water type, characteristic of water north of the Equatorial Front, persisted at the surface until August 1983. During this period in the upper 25 m temperatures exceeded 29°C and there were greatly reduced inorganic nutrients. The 60 m temperatures

reached a maximum of 28°C during June 1982, but at 60 m nutrients were never depleted. In March, April and May 1983 phytoplankton biomass, as indicated by chlorophyll *a*, was reduced to 30% of the mean quantity present in September, October, and November, 1983.

Resumen

Las medidas de temperatura, salinidad, nutrientes y clorofila tomadas periódicamente en una estación localizada en aguas de 100 m de profundidad en la Bahía Academia, Isla de Santa Cruz, definieron las condiciones oceanográficas durante el Niño en 1982/1983. Se colectaron muestras a los 0, 10, 25 y 60 m tres veces a la semana desde Junio 1982 a Diciembre 1983 para determinar los cambios oceanográficos. Las condiciones empezaron a cambiar a finales de Noviembre de 1982. Las temperaturas sobrepasaron 26°C y las concentraciones de nitrato, fosfatos y silicatos disminuyeron y la salinidad disminuyó a menos de $34^{\circ}/\text{oo}$. Este tipo de agua, característica de las aguas al norte del Frente Ecuatorial persistieron en la superficie hasta Agosto de 1983. Durante este período, en los primeros 25 m, las temperaturas excedieron 29°C y hubo una gran reducción de los nutrientes inorgánicos. A los 60 m las temperaturas alcanzaron un máximo de 28°C durante Junio de 1982, pero a los 60 m los nutrientes nunca se agotaron. En Marzo, Abril y Mayo de 1983 la biomasa de fitoplancton, indicado por el nivel de clorofila "a", se redujo al 30% del promedio presente en Septiembre, Octubre y Noviembre de 1983.

Introduction

The equatorial ocean off Ecuador and around the Galápagos Islands is an area of dramatic variability in both the physical environment and the biota. The variability of the physical properties and phytoplankton, on time scales from several days to several years, cannot all be explained by variations in the local wind and has been attributed to remote forcing, especially equatorial disturbances generated in the central Pacific. How, and to what extent, do propagating disturbances, advective fluctuations in water properties, or variations in the local meteorology affect water column stability and nutrient supply and, hence, the phytoplankton productivity that is the basis of the marine ecosystem? To help answer these questions a time series study was conducted in Academy Bay, Galápagos Islands from June 1982 through mid-December 1983 (fig. 1). This study together with a parallel time series in Paíta, Peru was designed to document the "normal" or non-El Niño spectrum of variability, but the possibility that El Niño might occur was considered as the design of the study developed. Both time series stations started on the same day in June 1982 and by September 1982 the stations had been in operation for several months so they were well prepared to document the dramatic changes that were to unfold between September 1982 and July 1983. This report describes the oceanographic changes observed at the Academy Bay time series station in the Galápagos Islands during 1982 and 1983.

Background

There is ample evidence for year-to-year variations in phytoplankton productivity in the waters of the Galápagos Islands (Jimenez 1981,

Cowles et al. 1977) but it has not been established what environmental forcing, if any, is responsible for the observed interannual variations. During the equatorial warming event of 1975 (Wyrtki et al. 1976) anomalously warm water west of the Galápagos Islands at 95°W was

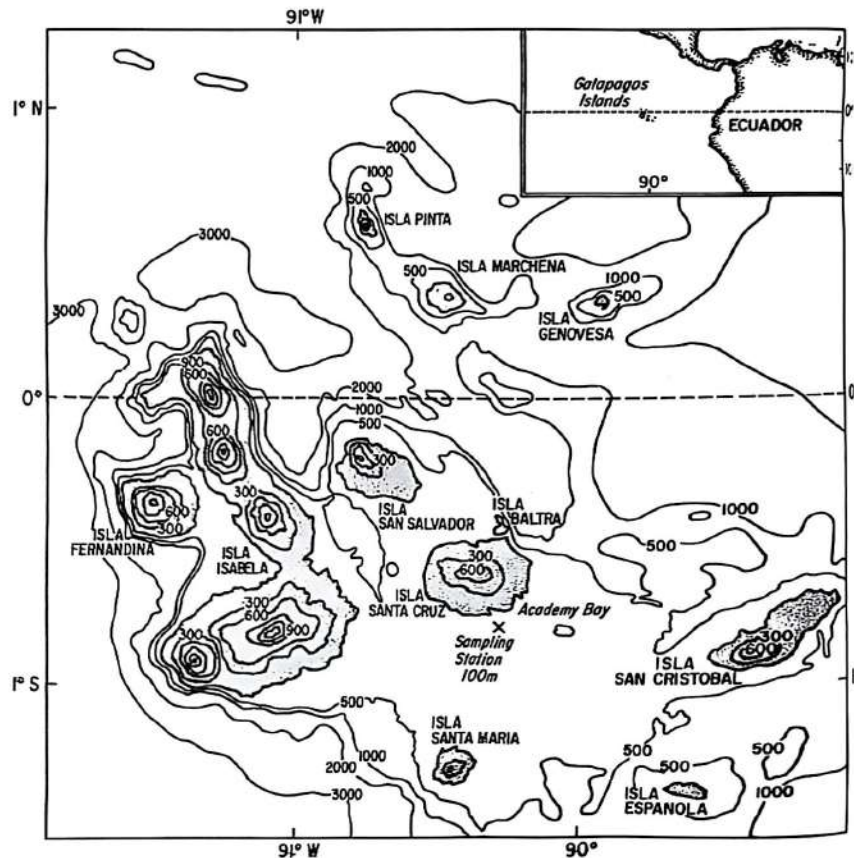


Fig. 1. Chart of the Galápagos Islands, showing the location of the time series station (X) at Academy Bay, Isla Santa Cruz on the 100 m depth contour.

nutrient rich (Cowles et al. 1977), but primary productivity was reduced about tenfold from values in the 1960's at the same location and season. At the onset of the 1976 El Niño a sudden bloom of the dinoflagellate phytoplankter Gymnodinium splendens took place in the coastal waters of Ecuador (Jimenez, personal communication); our interpretation of that large-scale biological event was that a sudden warming of the nutrient rich surface layer increased the static stability and made possible the Gymnodinium splendens bloom.

Improvement of our understanding of the causality of these biological changes in the equatorial ocean was the major consideration in the design of this study. Anecdotal accounts from 1972, 1975 and 1976 reported that biological consequences of El Niño showed up almost simultaneously over very large regions, persisted for months, then rapidly disappeared. It was clear that it was necessary to sample the environment of plankton on the short time scale of days, as well as the low frequency time scale of year-to-year changes. To accomplish this a triweekly sampling (Monday, Wednesday, Friday) was carried out for seventeen months; this sampling frequency was a logistic compromise that resolved the phytoplankton response scale (days) but did not place too large a workload on the individual doing the sampling. Daily sampling would have been a more desirable frequency but we felt triweekly sampling would produce better quality data than the more hectic pace of daily sampling. Our philosophy was to keep the work at sea as simple as possible to ensure consistent and high quality measurements as well as keeping logistic costs low. The work at sea was done by two people from a small outboard powered boat equipped with a portable hand winch.

The reason for doing this study in the Galápagos Islands is obvious; the Galápagos are the only islands on the equator in the eastern Pacific. They are perfectly located for detecting disturbances propagating in the equatorial waveguide. The best site in the Galápagos for this study would have been the northwestern tip of Isabela (fig. 1), exactly on the equator and on a coast facing west. However, since that region of Isabella is uninhabited, the logistic costs ruled out that site. Academy Bay provided an acceptable site in terms of access to the open ocean, presence of the Charles Darwin Research Station (CDRS) and easy access by scheduled air service. Laboratory space at CDRS and excellent logistic support in the form of the numerous small boats of the CDRS fleet contributed greatly to the success of the study. Originally we planned to sample from shore on whatever pier or dock was available; this suggestion met with consistent and strong criticism on the grounds that chemistry of a water sample from a pier or dock is not representative of the surrounding large-scale conditions. Accepting the wisdom of this criticism, the time series station was located a few kilometers offshore on the 100 m depth contour (fig. 1). Eppley et al. (1978) showed that onshore-offshore gradients in phytoplankton and nutrients are closely related to the water depth, but not to distance offshore. Inshore of the 50 m depth range they found that the tidal activity and vertical eddy diffusion are the forcing variables for phytoplankton, rather than the advective or turbulence regime of the adjacent ocean. The station was placed over the 100 m contour to double the "50 m factor" and ensure that we were not sampling an inshore artifact. The Academy Bay ocean station (fig. 1) is about seven kilometers southwest of CDRS and three kilometers due south of the small island named Isla Caamaño.

Methods

Three times a week water samples were collected from 0, 10, 25 and 60 meters by five liter Niskin bottles and a bathythermograph (BT) was lowered to 60 m. The water samples were processed in the following manner at the Charles Darwin Research Station. From each Niskin bottle a subsample of 250 ml was filtered through a Gelman Type A glassfiber filter precoated with magnesium carbonate; after extraction with 90% acetone and centrifugation, chlorophyll *a* and phaeopigments were determined with a Turner Designs Model 10-005 fluorometer. On a second subsample ammonia was immediately determined using the Koroleff (1970) procedure. A subsample taken for salinity was analyzed on an Autosol Model 8400. A fourth subsample was preserved with mercuric chloride and sent biweekly to Instituto Nacional de Pesca (INP) in Guayaquil, where nitrate, nitrite, phosphate and silicate were determined by conventional (Strickland and Parsons 1969) methods. The final subsample for the determination of phytoplankton species abundance was preserved and also sent to INP. These analyses are still underway and will not be presented in this report. The time series data reported here were smoothed by Hanning (Blackman and Tukey 1958) but not otherwise processed to suppress tidal variability.

Results

El Niño is the appearance and persistence of anomalously warm water for 6-18 months in the eastern tropical Pacific Ocean; the 1982/83 El Niño in the Galápagos Islands is clearly evident in fig. 2B where the climatological mean sea surface temperature based on a 17-year (1965-1981) record from Academy Bay is compared with monthly

means from 1982 and 1983. Fig. 2 emphasizes that in the Galápagos the 1982/83 anomaly was a massive enhancement of the normal annual temperature cycle.

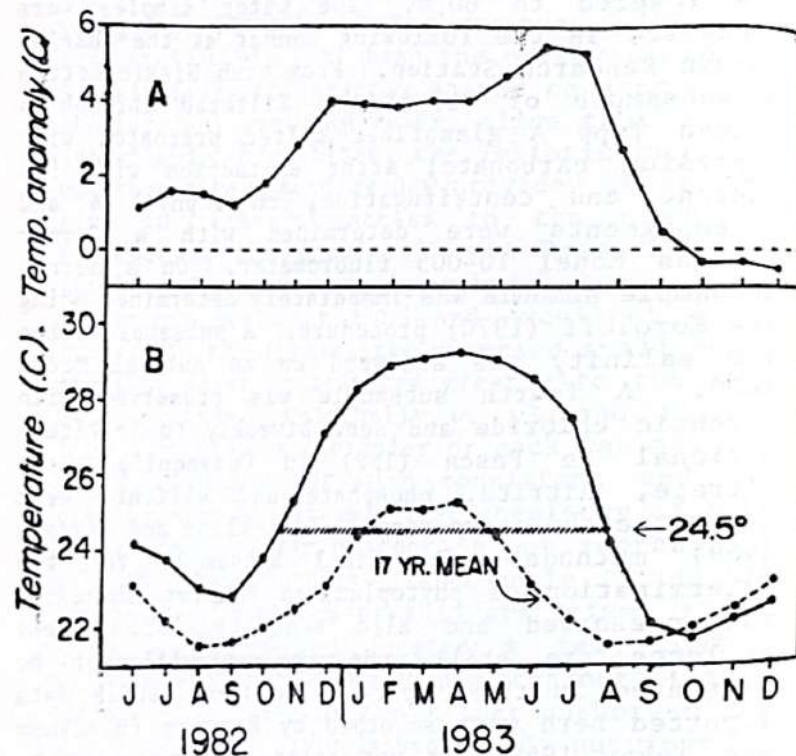


Fig. 2. (A) Temperature anomaly for Academy Bay during the 1982/83 El Niño. (B) Monthly mean temperature for 1982/83 plotted with 17 year monthly means for Academy Bay.

The rainy season in the Galápagos extends from January to May, with monthly mean rainfalls of greater than 20 mm; however, during this El Niño heavy rain fell from November 1982 through July 1983 (fig. 3). In fig. 2B the 24.5°C sea

surface temperature line intersects the normal January to May rainy season as well as the rainy season during the 1982/83 El Niño. It appears that in a normal year or an El Niño year, sea

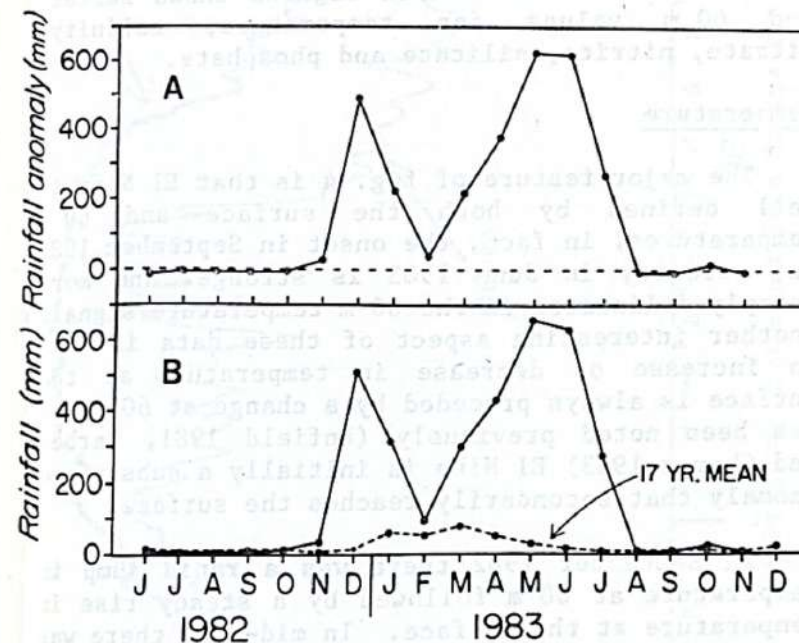


Fig. 3. (A) Rainfall anomaly at CDRS, Puerto Ayora, Isla Santa Cruz, during the 1982/83 El Niño. (B) Monthly mean rainfall for 1982/83 plotted with 17 year monthly means.

surface temperatures of 24.5°C will be accompanied by rain. One aspect of the rain anomaly (fig. 3A) not related to the sea surface temperature is the greatly decreased anomaly during the month of February 1983 when rainfall was only 35 mm above the climatological mean for that month. F. Chavez (personal communication) noted that the 60 m ocean

temperature anomaly also showed a clear minimum during that month, giving a 60 m temperature anomaly pattern that is bimodal and very similar in appearance to the rainfall anomaly.

The next series of six figures shows surface and 60 m values for temperature, salinity, nitrate, nitrite, silicate and phosphate.

Temperature

The major feature of fig. 4 is that El Niño is well defined by both the surface and 60 m temperatures, in fact, the onset in September 1982 and recovery in June 1983 is stronger and more sharply delineated in the 60 m temperature signal. Another interesting aspect of these data is that an increase or decrease in temperature at the surface is always preceded by a change at 60 m; as has been noted previously (Enfield 1981, Barber and Chavez 1983) El Niño is initially a subsurface anomaly that secondarily reaches the surface.

In September 1982 there was a rapid jump in temperature at 60 m followed by a steady rise in temperature at the surface. In mid-June there was a rapid decline in temperature at 60 m followed by further gradual cooling, but strong surface cooling didn't start until August 1983. In October 1983 the surface temperature stabilized at a value cooler than the climatological monthly mean, while the 60 m water continued to drop in temperature to below 15°C at the end of this time series study in December 1983.

Salinity

In contrast to the well defined 60 m temperature signal of El Niño, the 60 m salinity shows relatively little change during the anomaly.

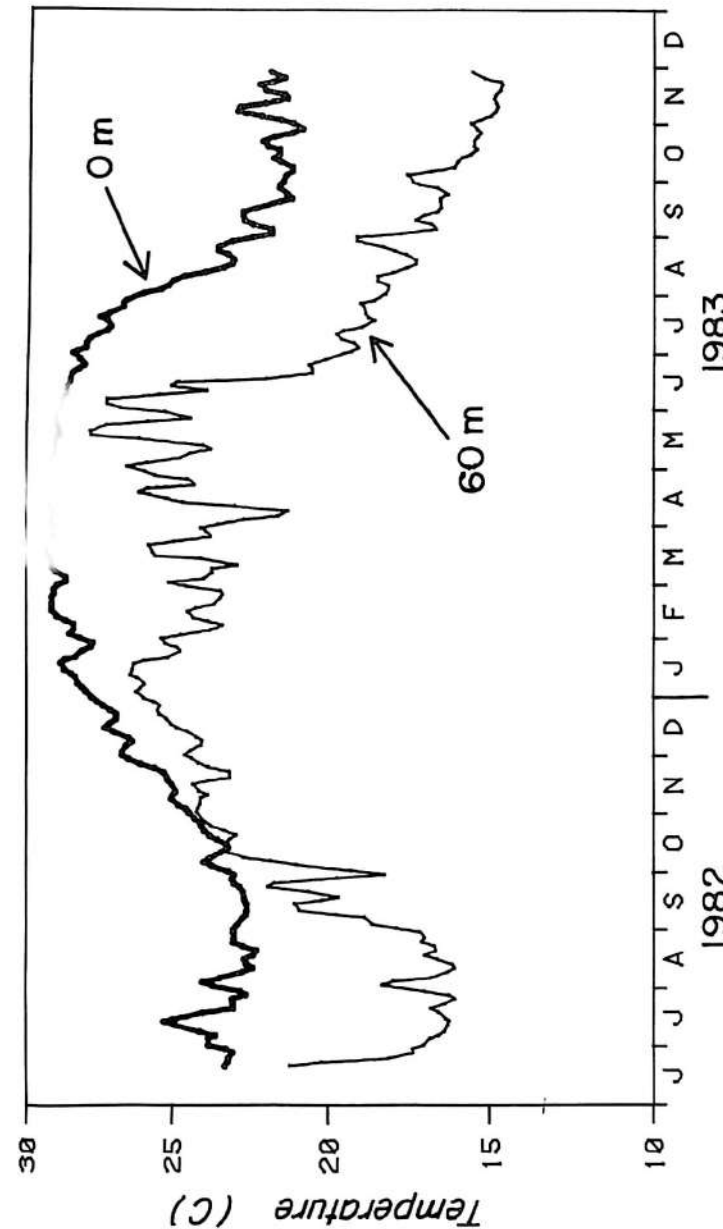


Fig. 4. Time series plot of temperature at 0 m and 60 m during the 1982/83 El Niño.

From October 1982 to April 1983 the 60 m salinity varied around $34.9^{\circ}/\text{oo}$ with no decreasing trend; in mid-April 1983 there was a decrease and for 2 months the salinity varied around $34.5^{\circ}/\text{oo}$. In mid-June salinities rose sharply and remained relatively constant just over $35.0^{\circ}/\text{oo}$ through December 1983.

The surface versus 60 m salinity relationship appears to be the opposite of the temperature relationship. For temperature, each surface change was preceded by a 60 m change suggesting that subsurface conditions are forcing, but the salinity relationship shows that for salt, unlike heat, conditions in the surface layer are independent from conditions at 60 m.

The episodes of rapid temperature rise in mid-September 1982 and throughout October 1982 are shown by the surface and 60 m salinity time series in fig. 5 to be periods of intense mixing. The October 1982 period is the only time when the water column was isohaline for an extended period. Nitrate (fig. 6) and phosphate (fig. 9) further confirm that the water column was homogeneous during the onset of El Niño in October 1982. At the end of November 1982, coincident with the beginning of heavy rainfall, surface salinity decreased and remained low and variable ($33.0^{\circ}/\text{oo}$ to $34.0^{\circ}/\text{oo}$) until August 1983. In August 1983 surface salinity increased from the El Niño condition, but showed surprisingly large variability. For a short period in November 1983 salinity fell below $34.0^{\circ}/\text{oo}$.

Nutrients

The temporal pattern of variability in nitrate (fig. 6) shows most emphatically why El Niño has a large impact on the marine ecosystem of the

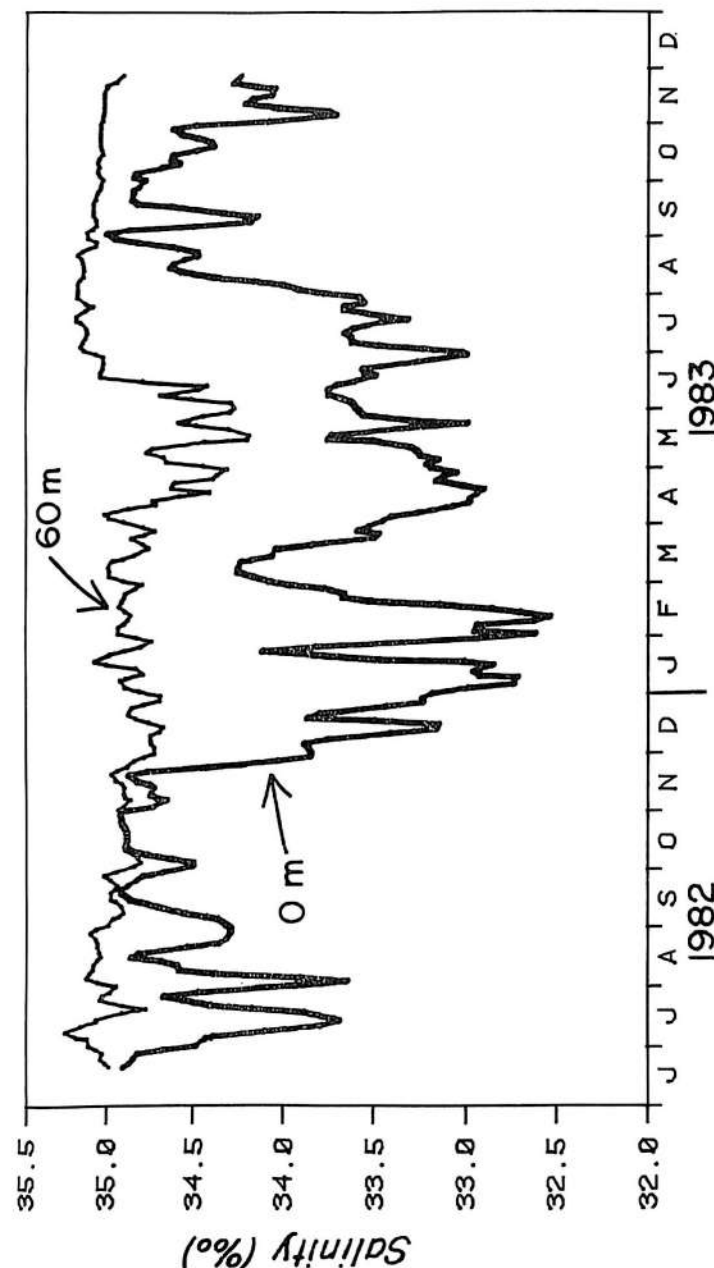


Fig. 5. Time series plot of salinity at 0 m and 60 m during the 1982/83 El Niño.

Galápagos Islands. The surface layer values at the beginning and end of this time series show that nitrate values of 2 to 6 μM prevailed. The relationship between growth and ambient nutrient concentration is complex (Dugdale et al. 1981) but for the purpose of this description of El Niño it is adequate to know that nitrate concentrations from 2 to 6 μM constitute nutrient rich conditions where the uptake versus concentration relationship is saturated. Fig. 6 shows that, in the absence of El Niño, Galápagos waters are nutrient rich, that is, there are saturating concentrations of nitrate in the surface layer most of the time. Fig. 6 shows that there are brief episodes of nutrient depletion as occurred in mid-July 1982 and early August 1982 but the prevailing non-El Niño condition is nutrient rich and highly variable. The regular variability both before and after the anomaly suggest to us that tidal destratification rather than upwelling may be the physical mechanism responsible for supplying nutrients to the surface.

The pre-El Niño period (June, July, August 1982) had a consistent surface temperature anomaly (fig. 2A) of about 1.0 to 1.5°C but clearly was not nitrate depleted. The post-El Niño period of October, November, December 1983 had a slight negative temperature anomaly (fig. 2A) but very similar nitrate concentrations (fig. 6). This result indicates that water of a similar nitrate (and salt) concentration had a higher heat content in the pre-El Niño period than it had in the post-El Niño period. We have found this to be true at other locations in the eastern tropical Pacific (Barber et al. 1983). The surface concentration of nitrate for six and one-half months, from December 1982 to mid-June 1983, was very low, often below the detection limit of 0.02 μM . Such concentrations are clearly nutrient

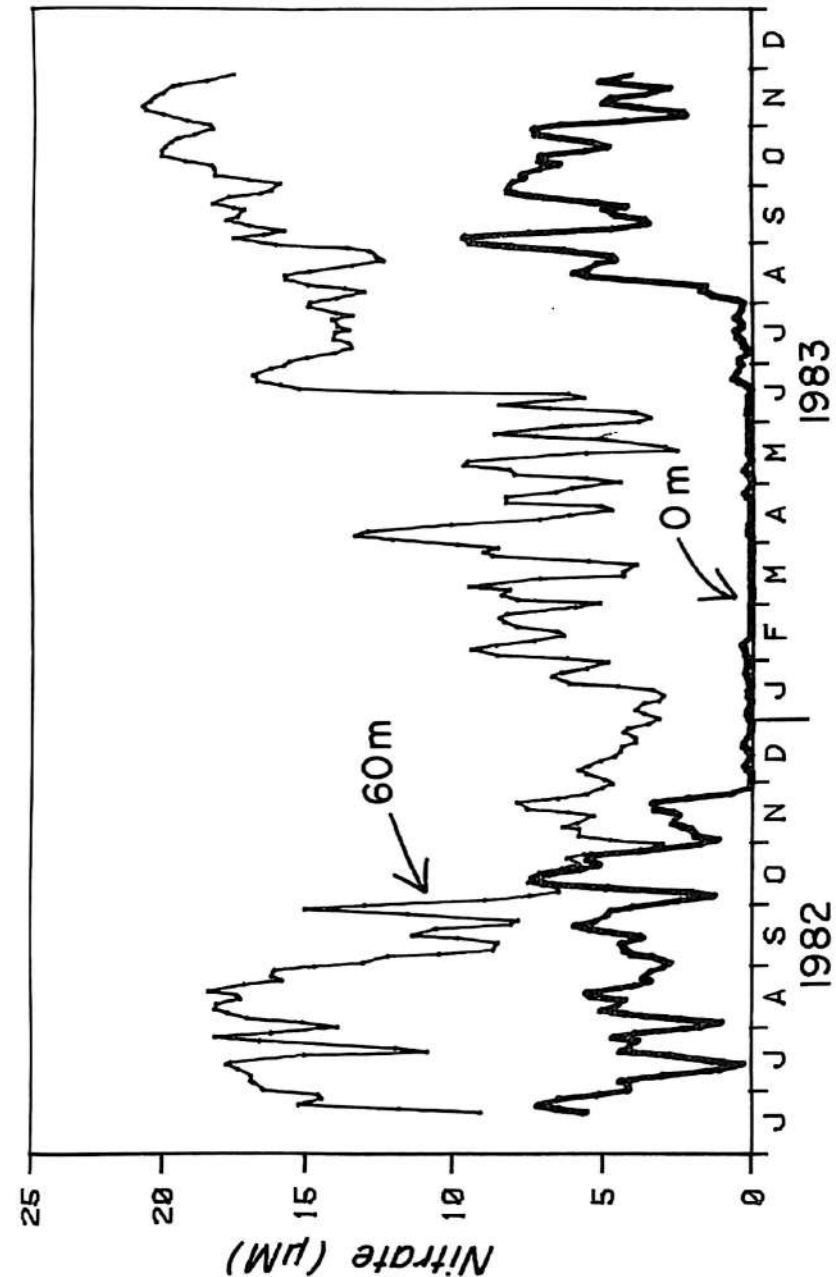


Fig. 6. Time series of nitrate at 0 m and 60 m during the 1982/83 El Niño.

poor and will necessarily decrease the new production as defined by Dugdale and Goering (1967).

The regularity of the 60 m nitrate variability between December 1982 and June 1983 seems to be further evidence of tidal forcing, but none of the 60 m enhancement reached the surface during this period.

Nitrite (fig. 7) is, of course, much less abundant than nitrate, but the surface concentration shows a consistent decrease during the anomaly with a minimum in May and June 1983 when concentrations were below detection. The increase in nitrite at 60 m during the anomaly appears to be an enhancement of the primary nitrite maximum at the base of the euphotic zone (60 m). Such an increase most likely resulted from light limited phytoplankton excreting nitrite after taking up the abundant nitrate that was present at 60 m throughout the anomaly (Kiefer et al. 1976).

Silicate (fig. 8) and phosphate (fig. 9) plots shows that these nutrients covary with nitrate at the surface and 60 m, but unlike nitrate, they were never depleted in the surface layer. These data emphasize that there is an atom ratio excess of phosphate-phosphorus and silicate-silicon relative to nitrate-nitrogen. Fig. 10 shows that the nitrate to silicate ratio covaries with the surface salinity; in the pre- and post-El Niño period when surface salinity was always over 34.0‰ the nitrate to silicate ratio varied between 0.5 and 1.5; when surface salinity decreased at the end of November 1982 the ratio decreased to a very low value. At the end of July 1983 both properties rose sharply to the previous levels.

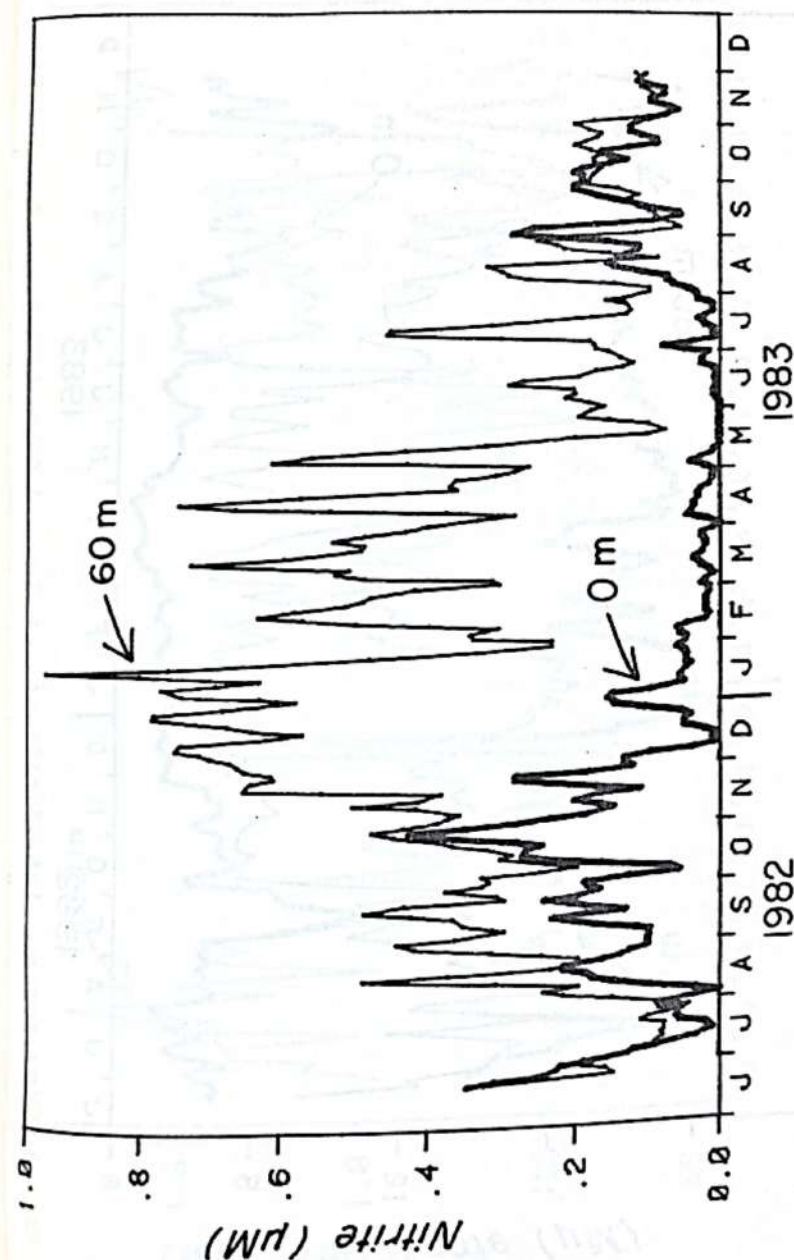


Fig. 7. Time series plot of nitrite at 0 m and 60 m during the 1982/83 El Niño

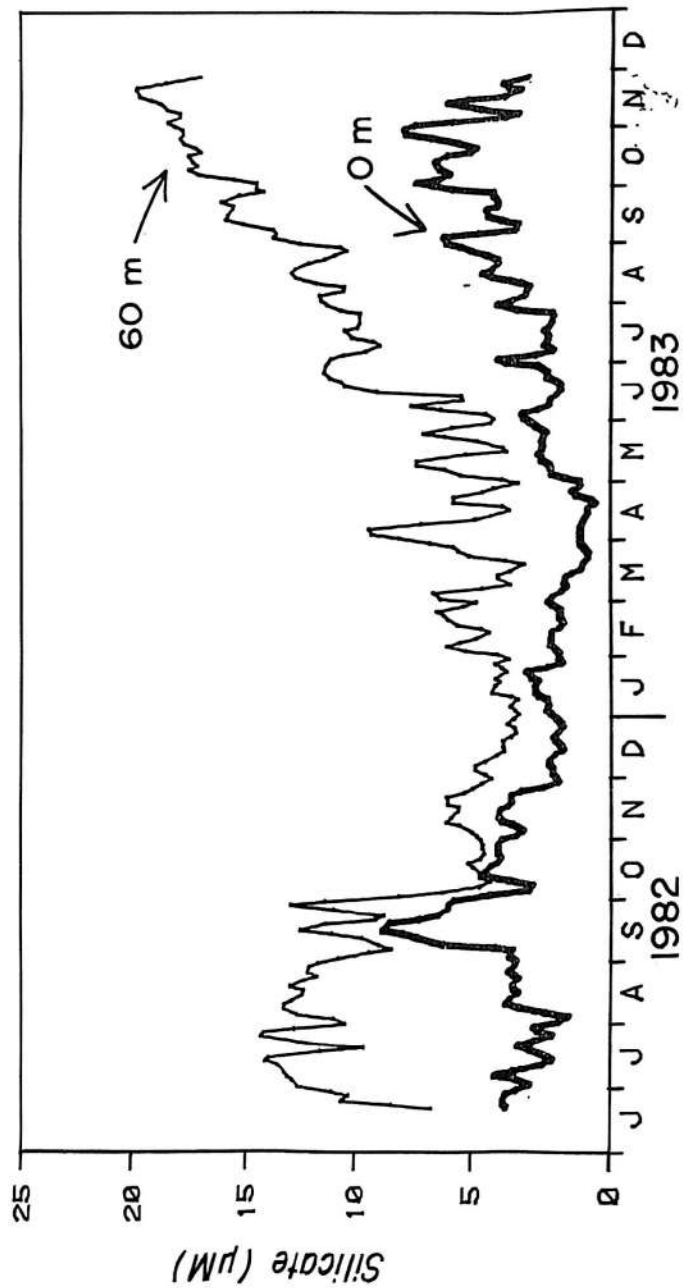


Fig. 8. Time series plot of silicate at 0 m and 60 m during the 1982/83 El Niño.

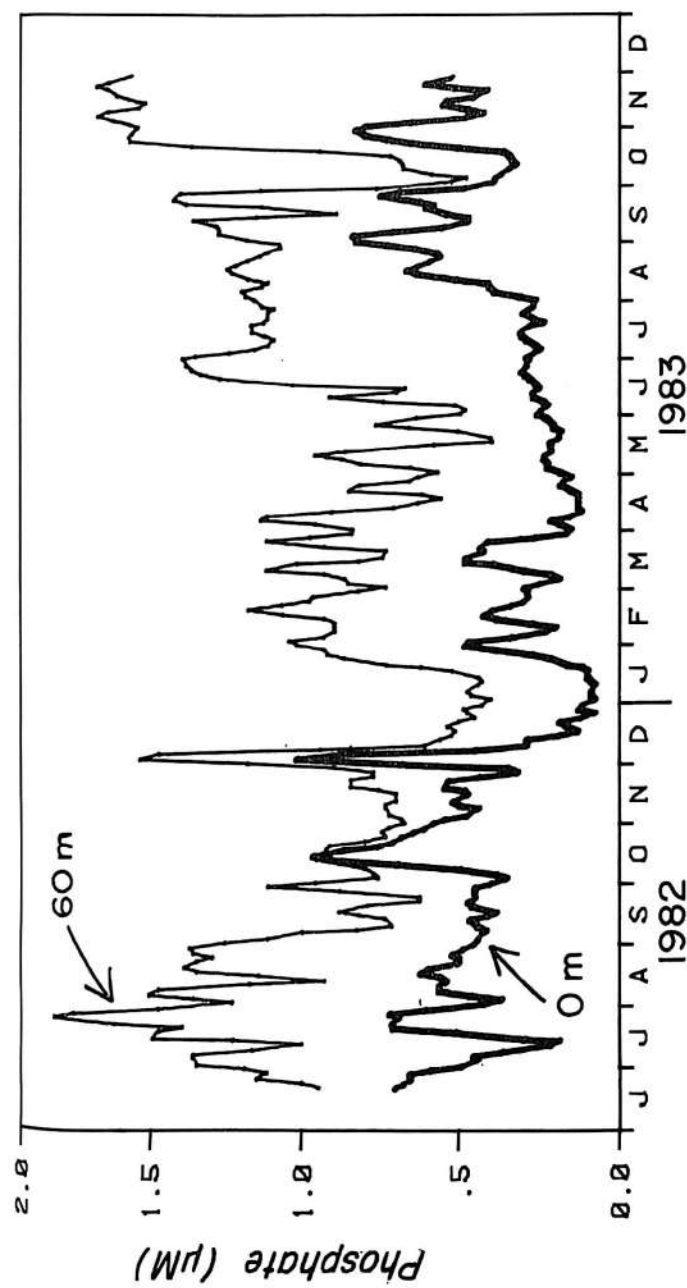


Fig. 9. Time series plot of phosphate at 0 m and 60 m during the 1982/83 El Niño

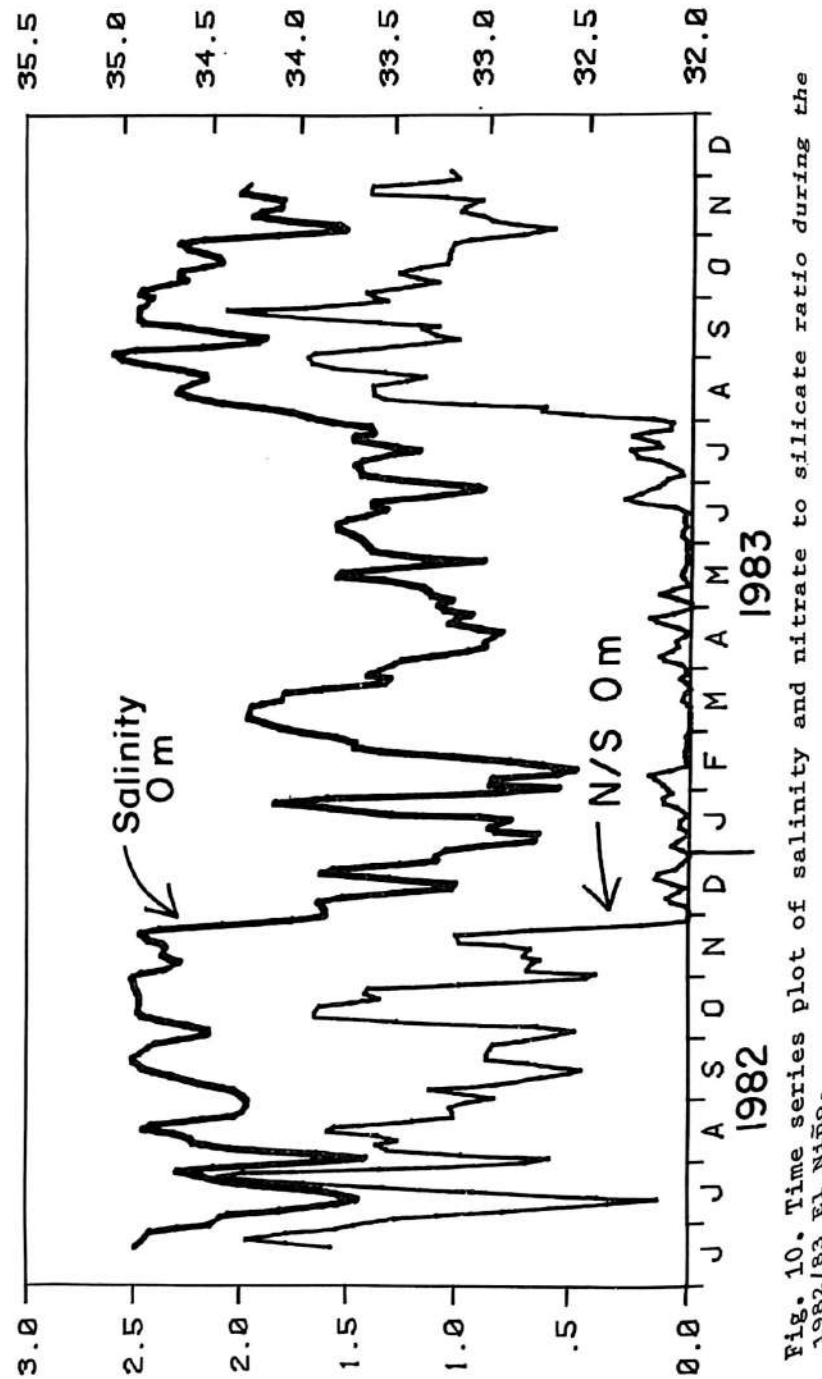


Fig. 10. Time series plot of salinity and nitrate to silicate ratio during the 1982/83 El Niño.

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The surface ammonia concentration (fig. 11) certainly does not decrease during the anomaly and, in fact, it appears as though there is a slight increase in ammonia from March 1983 to July 1983. These levels of ammonia indicate that recycled nitrogen was available at moderate levels throughout the anomaly. In this characteristic, the Galápagos waters were typical tropical surface waters for six and one-half months with virtually no new nitrogen in the form of nitrate, but a continuous supply of recycled nitrogen in the form of ammonia.

Chlorophyll

The time series plot of surface chlorophyll (fig. 12) showed remarkably little change through the course of the anomaly. During the height of the anomaly (March, April and May 1983) the mean concentration of chlorophyll was $0.4 \mu\text{g/l}$ or about 30% of the mean value during the post-El Niño period of September, October, and November 1983, but this reduction results from the elimination of the periodic blooms rather than a downward shift of the baseline concentration. Recycling ammonia was apparently adequate to maintain a baseline phytoplankton abundance of about $0.4 \mu\text{g/l}$ chlorophyll, but from February 1983 to June 1983 no blooms with over $1.0 \mu\text{g/l}$ chlorophyll developed. Despite the absence of the typical periodic blooms, the overriding impression from the chlorophyll time series is that El Niño had a relatively modest impact on the quantity of phytoplankton. On the other hand the phytoplankton species samples that are still being analyzed by Roberto Jiménez of INP appear to indicate that there were significant changes in the kind of phytoplankton.

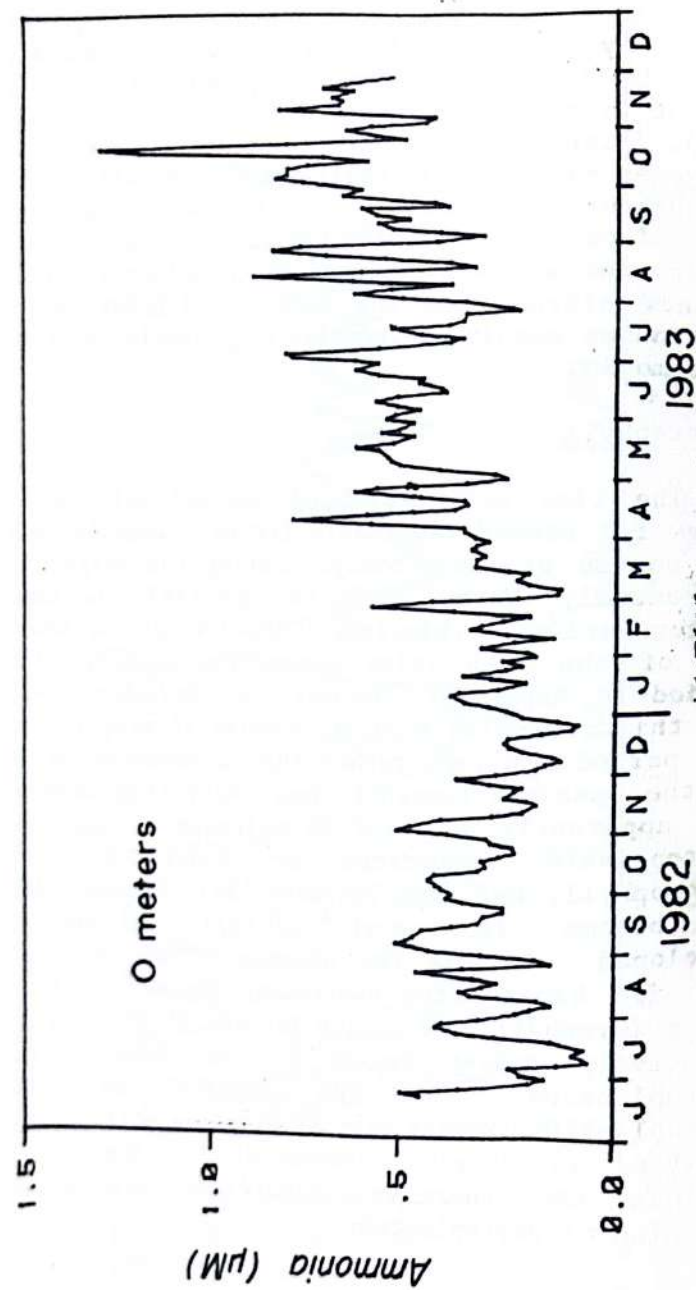


Fig. 11. Time series plot of surface ammonia during the 1982/83 El Niño.

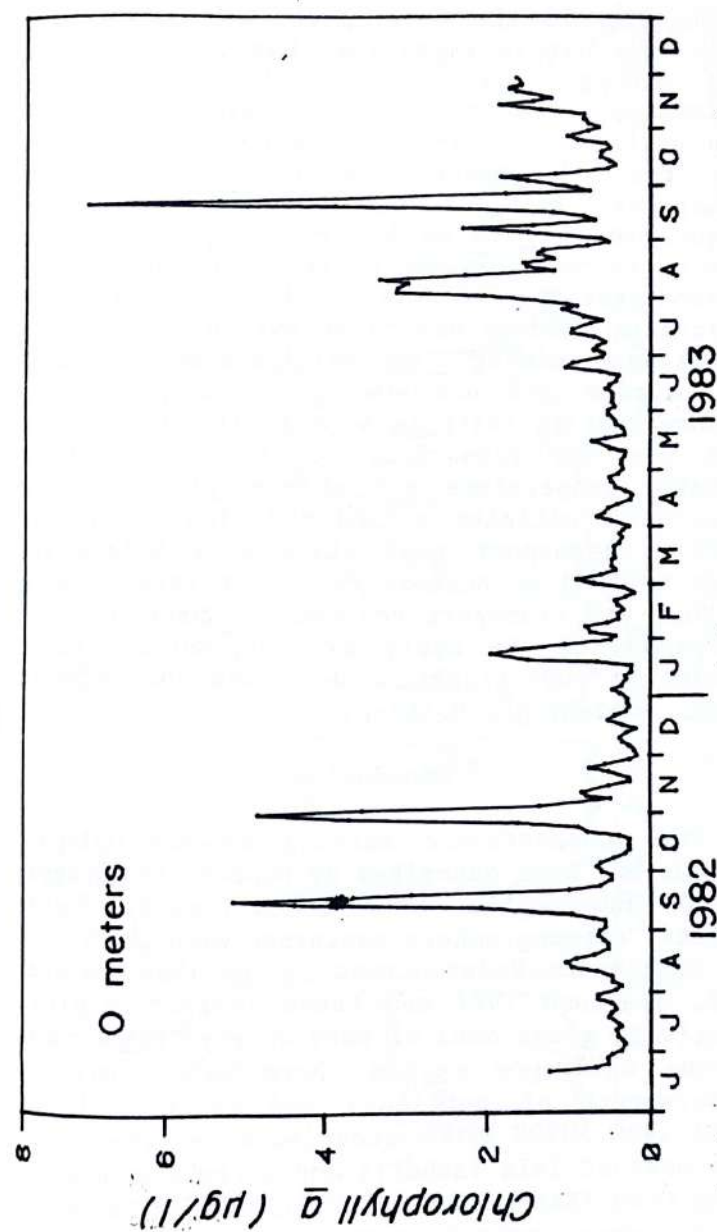


Fig. 12. Time series plot of surface chlorophyll *a* during the 1982/83 El Niño

In fig. 13 the chlorophyll and salinity are shown together to emphasize that the blooms with over $4.0 \mu\text{g/l}$ chlorophyll occur when surface salinities are over 34.9°oo . Examination of the mean salinity distributions in Lukas (1981) shows that the only source for over 34.9°oo water either east (85°W) or west (95°W) of the Galápagos Islands in the 5°S to 5°N band is subsurface at 50 m or deeper. On the basis of this information we interpret the presence of 34.9°oo water at the surface at Academy Bay to be evidence of previous upwelling or mixing. Recognizing that temperature and nitrate are nonconservative properties, it appears that salinity is a good indicator of water that has had subsurface origin. The modified nitrate, temperature and chlorophyll content of these high salinity episodes indicates that the vertical transport took place well before this water arrived at Academy Bay. Our interpretation is that the transport took place upstream of the Galápagos and the newly surfaced water with its developing phytoplankton bloom was then advected by the Academy Bay station.

Discussion

The oceanographic setting of the Galápagos Islands has been described by Wooster and Hedgpeth (1966), Houvenaghel (1978) as well as by numerous physical oceanographers concerned with the fate of the Equatorial Undercurrent (White 1969, Zaneveld 1972, Anderson 1977 and Lukas 1981). Despite a relatively great deal of work on physical dynamics of the Galápagos region there exists only few measurements of nutrients and chlorophyll. In April 1966 ANTON BRUUN occupied a section on 92°W just west of Isla Isabella and a few stations near Tagus Cove (Barber and Ryther 1969); in March 1968 TE VEGA made several stations among the Galápagos Islands (Barber and Norton 1968) and in 1971 the

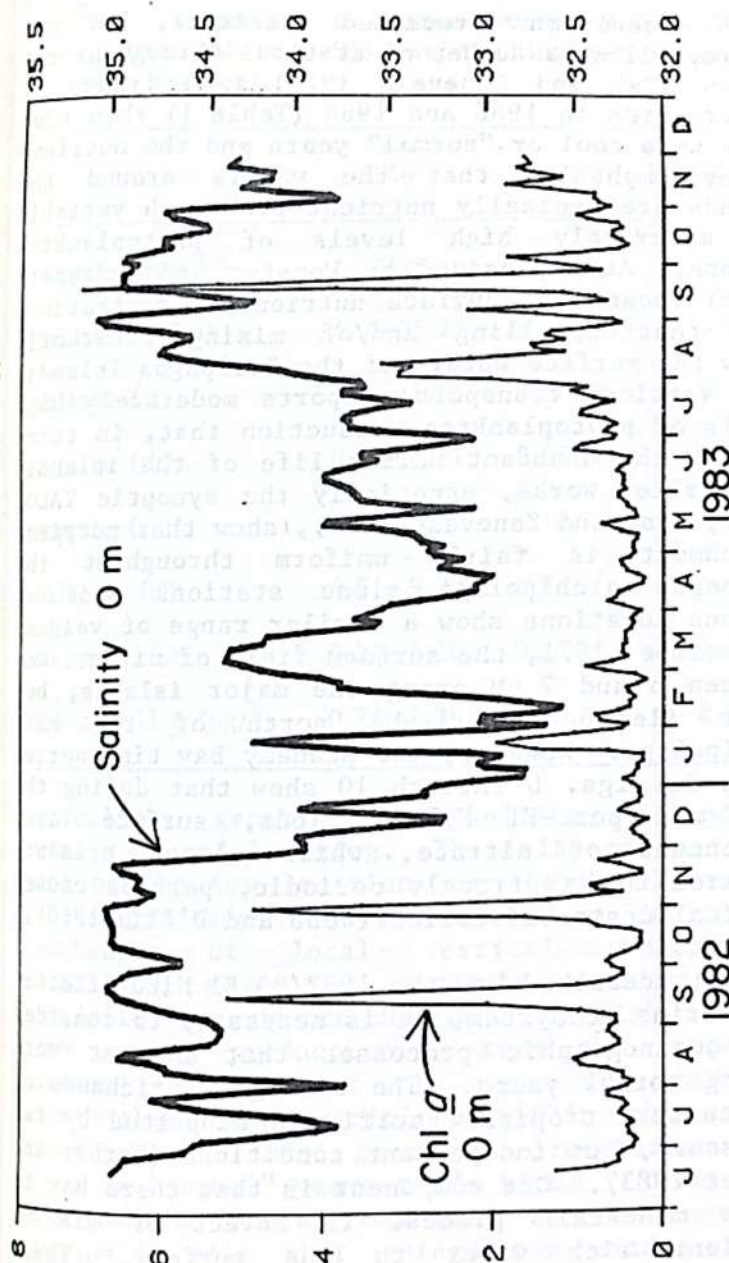


Fig. 13. Time series plot of surface salinity and surface chlorophyll during the 1982/83 El Niño.

YALOC expedition determined nutrients, but not chlorophyll at a number of stations throughout the region (Pak and Zaneveld 1974). The range of temperatures in 1966 and 1968 (Table 1) show that these were cool or "normal" years and the nutrient ranges emphasize that the waters around the islands are typically nutrient rich with variable but moderately high levels of phytoplankton biomass. As emphasized by Wooster and Hedgepeth (1966) these high surface nutrient concentrations show that upwelling and/or mixing constantly renew the surface waters of the Galápagos Islands. This vertical transport supports moderately high levels of phytoplankton production that, in turn, support the abundant marine life of the islands. The earlier works, especially the synoptic YALOC survey (Pak and Zaneveld 1974), show that nutrient enrichment is fairly uniform throughout the Galápagos archipelago since stations made at various locations show a similar range of values. In November 1971, the surface field of nitrate was between 5 and 7 μM among the major islands, but lower (less than 1 μM) north of the main archipelago. However, the Academy Bay time series plots in figs. 6 through 10 show that during the pre- and post-El Niño periods, surface layer enrichment of nitrate, while always present, appeared to be strongly periodic, perhaps caused by tidal destratification (Webb and D'Elia 1980).

To understand how the 1982/83 El Niño affected the marine ecosystem, it is necessary to consider the oceanographic processes that are at work during normal years. The biological richness of the eastern tropical Pacific is supported by two necessary, but independent conditions (Barber and Chavez 1983). One component is that there has to be a mesoscale process to advect or mix up nutrient rich water to the surface. These processes can be wind driven coastal or equatorial

Table 1. Comparison of surface properties in April 1966, March 1968 and the 1983 post-El Niño period (September, October, November).

	1966	1968	1983-post-E.N.
Temperature ($^{\circ}\text{C}$)	21-25	21-25	21-24
Salinity ($^{\circ}/\text{oo}$)	34.95-35.27	33.72-34.76	33.50-35.04
Nitrate (μM)	3.0 -11.8	0.9 - 5.6	0.8 -11.0
Nitrite (μM)	0.14- 0.41	0.09- 0.22	0.04- 0.32
Ammonia (μM)	1.1 - 3.0	N.A.	0.2 - 1.6
Silicate (μM)	4.5 - 9.3	6.7 -16.1	1.9 - 9.7
Phosphate (μM)	0.24- 1.16	0.20- 0.81	0.28- 0.92
Chlorophyll <i>a</i> ($\mu\text{g/l}$)	0.24- 2.76	N.A.	0.34-10.52

upwelling, geostrophic upwelling, island wake mixing or tidal mixing. The Galápagos waters are one of the few locations in the world where all these processes may be at work. Whatever the mechanism of local vertical transport of nutrients, a second condition that has to be satisfied to support continuously high levels of new primary production is that the large-scale thermal structure of the ocean must bring the thermocline and nutricline within the vertical reach of the local transport processes. During cool or "normal" years trade winds blowing across the Pacific Ocean from east to west set up a basinwide tilt that brings the middle of the thermocline (the 20 $^{\circ}\text{C}$ isotherm) and the nutricline

to a relatively shallow depth of 40 m or less in the Galápagos region. With the nutricline so shallow even modest upwelling or mixing can transport a significant supply of nutrients to the surface layer and support enhanced levels of new production.

Early descriptions of El Niño assumed that upwelling ceased because cool sea surface temperatures, which were the major evidence of upwelling, disappeared during El Niño (Wooster and Guillen 1974). When wind data became available it became clear that in previous El Niño events (Enfield 1981) and in the 1982/83 El Niño (Smith 1983) the wind driven upwelling along the coast of Peru did not substantially weaken through March 1983. During El Niño it appears that wind driven coastal upwelling may continue but the water entrained by the upwelling circulation is warm and low in nutrients because the thermocline and nutricline are progressively depressed. Because the meridional component of wind stress along the coast of Peru remained strong enough to force some coastal upwelling through March 1983 (Smith 1983), but the basinwide nutricline was depressed, nitrate at the Paíta time series station showed a progressive decline rather than the sharp decrease seen at the Galápagos (fig. 6). Winds at Puerto Ayora started to decrease in strength in January 1983 but by that time the oceanographic anomalies were well established at Academy Bay. The sharp decline in surface nitrate at the end of November 1982, when the local winds were essentially unchanged, indicates that the major causal factor for the nutrient variability was nutricline depression not a decrease in locally forced upwelling or mixing.

Evidence of continuing subsurface enrichment processes at work throughout the 1982/73 El Niño

is seen in fig. 6. The 60 m nitrate shows a pattern of variability from January to June 1983 that is similar to the pattern of variability at the surface in the pre- and post-El Niño nitrate. Fig. 6 shows, however, that the periodic 60 m enrichment did not get to the surface during the anomaly from January to June 1983.

The Academy Bay time series plots show that at the end of November 1982 after two months of intense mixing, a strong halocline developed between the surface and 60 m; surface salinities were usually below $34.0^{\circ}/\text{oo}$ and 60 m values were always above $34.2^{\circ}/\text{oo}$. This strong density gradient remained in place until July 1983 and was in itself a strong barrier to vertical exchange. In this context the onset of El Niño (September, October and November 1982) appears to be oceanographically distinct from the mature phase of the anomaly (December 1982 through June 1983). During onset surface and subsurface temperatures were increasing, the 0 to 60 m water column was well mixed, nutrients were present in "normal" concentrations at the surface (2-6 μM nitrate), but 60 m nitrate (fig. 6) was sharply reduced due to depression of the nutricline. Note that during onset in October 1982 the highest chlorophyll concentration was present (fig. 12); this bloom on the shelf of the Galápagos archipelago contrasts with the greatly reduced phytoplankton biomass that was present offshore to the west in the equatorial Pacific (Barber and Chavez 1983).

The most significant oceanographic change of El Niño appears to be nutrient depletion. The concentration of nutrients in the surface was significantly reduced from December 1982 to June 1983 and this depletion of new nutrients necessarily reduced the new primary production (Dugdale and Goering 1967, Eppley and Peterson

1979). After a period of time the decrease in new primary production must have caused proportional reductions in the growth and reproductive success of zooplankton, fish, birds and marine mammals.

Acknowledgements

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SATELLITES, SEABIRDS, AND SEALS*

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Long Island, New York 11794

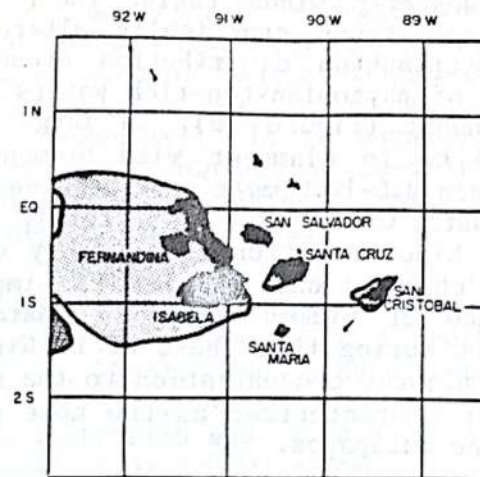
The conditions for, and the unique character of, life on the Galápagos Islands is directly related to the oceanographic setting and the biological productivity of the surrounding waters. Variations in ocean conditions have been shown to have profound effects on the biota of these islands, particularly during times of El Niño (Boersma, 1978). A recent investigation, utilizing satellite ocean color observations and complemented with coincident oceanographic measurements has demonstrated the tight coupling that exists between the distribution of phytoplankton populations around the Galápagos Islands and the oceanographic conditions observed during the 1982-83 El Niño (Feldman, Clark, & Halpern 1984). The reversal of winds and ocean currents during February-March, 1983 is associated with a major redistribution of food resources around the archipelago. This redistribution, combined with a decrease in primary productivity of the region (Barber & Chavez, 1983), might explain the observed reproductive failure of seabirds and marine mammals on the Galápagos Islands during this El Niño.

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Atmosphere Newsletter.

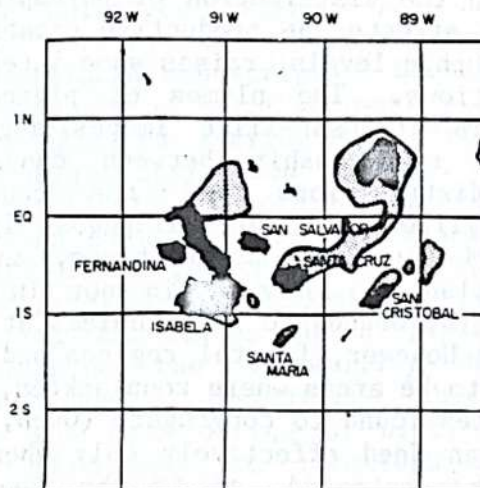
Barber and Chavez (1983) have noted that ocean waters around islands have inherently higher productivity than waters far removed from land. This increased productivity depends mainly on the supply of nutrients to the euphotic zone. Vertical mixing in the island wakes, often in the form of eddies, provides one mechanism that can explain the regions of high primary production associated with oceanic islands. Maxwell (1974) concluded that for the marine life in the Galápagos, the patterns of upwellings are instrumental in maintaining the lower trophic levels which in turn supply the higher carnivores (ie. seabirds and marine mammals) with food. It is the variability in these patterns that satellite ocean color observations with their broad spatial and high temporal resolution allows us to monitor.

The phytoplankton pigment distributions around the Galápagos Islands for 1 February and 28 March 1983, which were derived from Nimbus-7 Coastal Zone Color Scanner (CZCS) imagery are presented in Figure 1. A detailed discussion of the imagery and of the oceanographic conditions that were observed during that period can be found in Feldman, Clark, and Halpern (1984). On 1 February 1983, a plume with pigment concentrations greater than 1.5 mg/m^3 extends approximately 150 km to the west of Isabela (Figure 1A). The appearance of cold subsurface water and strong westward flows throughout the euphotic zone indicated that conditions were apparently returning to normal during this period. In fact, the patterns observed on 1 February correspond closely with those found in past CZCS images and shipboard observations made during non-Niño conditions (note Figure 14 in Maxwell, 1974).

By the end of March, at the peak of the 1982-83 El Niño, there was a resurgence of strong eastward flow along the equator. In addition, there was a collapse of the trade winds in the eastern Pacific



1A



1B

Figure 1. Graphic representation of the phytoplankton pigment concentrations around the Galapagos Islands derived from Nimbus-7 Coastal Zone Color Scanner imagery on (A) 1 February 1983 and (B) 28 March 1983. The lightly shaded areas represent pigment concentrations greater than 1.0 mg/m^3 . The darkly shaded area seen in (B) represents pigment concentrations between $3.0\text{--}10.0 \text{ mg/m}^3$. In general, concentrations of less than 0.2 mg/m^3 were found throughout the region.

with anomalous westerly winds taking their place. These changing conditions drastically altered the patterns of phytoplankton distribution around the islands. Plumes of phytoplankton-rich waters extend toward the northeast (Figure 1B). A large patch, approximately 60 km in diameter with pigment concentrations between 3.0-10.0 mg/m³ can be seen to the northeast of Santa Cruz. These patterns, representing peak El Niño conditions are highly unusual based upon past observations. Perhaps as important as the appearance of plumes of phytoplankton-rich water to the east during this phase of El Niño, was the decrease in pigment concentration to the west of Isabela, normally characterized as the most productive region in the Galápagos.

This evidence of the dramatic effect that El Niño can have on the distribution of phytoplankton, which ultimately affects the productive capabilities of the higher trophic levels, raises some interesting ecological questions. The plumes of pigment-rich water evident in the satellite images suggest a possible causal relationship between changes in phytoplankton distributions and the conditions necessary for life on the Galápagos Islands. Satellite-derived pigment concentrations, an indicator of phytoplankton biomass, is not in itself an indicator of the abundance of organisms at higher trophic levels. However, frontal regions and eddies have been shown to be areas where zooplankton, squid, and fish are often found to congregate (Owen, 1981). Many seabirds can feed effectively only when their prey has been concentrated, as is the case along frontal zones (Ashmole, 1971).

Perhaps it is the persistence of regions of high primary production, rather than the absolute magnitude that is important to the higher trophic levels. The short-term (days-weeks) spatial variability evident in the satellite-derived pigment distributions are probably responses to changes in such short-term physical processes as winds, tides,

and small fluctuations in the strength and direction of current flows. A region of high production may move about some central position in response to these events, while the mean location remains relatively stable throughout the longer time scales (weeks-months). It is changes over the time frame of weeks to months, as seen in Figure 1, which may produce the most significant effects on organisms at higher trophic levels.

The catastrophic reproductive failure of seabirds and marine mammals during El Niño has been well documented (Schreiber & Schreiber, 1983; Limberger et al., 1983). Researchers point toward a disruption in the normal food web and the disappearance of the small fish and squid which are the usual prey for these species as the prime cause. Short-term growth fluctuations for several species of seabirds on the Galápagos Islands have been related to the availability of food resources (R. Ricklefs, unpublished manuscript). During the breeding season the foraging range of many species of seabirds is very limited leaving the birds susceptible to any major redistribution of food. Breeding strategies, particularly the location of nesting colonies and the season in which breeding occurs, have been optimized over many generations through natural selection (Boersma, 1978); therefore, the long-term environmental conditions at a particular location will determine the suitability of that site. When environmental conditions change dramatically, as is the case during El Niño, populations that are tied to specific locations and therefore unable to exploit a geographic redistribution of food resources may suffer reproductive failures.

Satellite ocean color observations with their synoptic, broad areal coverage places the often limited surface measurements into a broader perspective. This new perspective allows us to refine our interpretation of the ecological consequences of the physical changes that take place in the ocean.

An investigation of the spatial and temporal variability of CZCS-derived phytoplankton distributions in the eastern equatorial Pacific, including the coastal upwelling regions, beginning in 1978 and continuing through the 1982-83 El Niño is now underway.

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PARTE II

EL NIÑO EN GALAPAGOS

EL NIÑO IN GALAPAGOS

THE NATURE OF EL NIÑO:
A PERSPECTIVE

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Summary

The following pages relate my experiences and observations during the most extreme El Niño season of which there are records. The changes wrought in the climate brought about major changes in population size for some organisms and others were forced to flee the islands in search of sufficient food for survival, for the seas of the eastern Pacific became impoverished. The regular patterns of distribution of many animals were disrupted and there would appear to have been some powerful selection pressures brought to bear on several species. One wonders how much Niño years have been responsible for the remarkable assemblage of organisms which now exist within the archipelago.

It was my fortune to be working as a National Park Naturalist Guide within the islands during this period and it has left a deep impression on me for the rapidity with which changes took place and the differing abilities of creatures and plants to deal with them. Are these organisms finely adapted or are they the victims of fate and chance?

Resumen

Las siguientes páginas relatan mis experiencias y observaciones durante una de las temporadas más extremas, de las que constan en record, del fenómeno El Niño. Las alteraciones en el clima dieron como resultado grandes cambios en el tamaño de las poblaciones de algunos organismos y otros fueron forzados a huir de las islas en busca de alimento suficiente para sobrevivir, ya que el Pacífico del este se tornó sumamente pobre. Las normas regulares de vida de muchos animales fueron interrumpidas y parece que ha habido fuertes presiones de selección natural para algunas especies. Uno se pregunta: ¿Hasta qué punto los años en que ha ocurrido el fenómeno del Niño son responsables de la extraordinaria presencia de organismos que existen ahora en el archipiélago?

Fue mi suerte el haber estado trabajando como Guía Naturalista del Parque Nacional Galápagos durante este período y ha dejado en mí una muy profunda impresión de la rapidez con la que los cambios ocurrieron y la habilidad con la que animales y plantas se enfrentaron a este fenómeno. ¿Están estos organismos finamente adaptados o son víctimas del destino y el azar?

On a mid-September day of 1983, I sit at my table in an old house built of lava blocks, whilst a gentle, cool southeast breeze tempers the heat of the tropical sun. A few feet away, the sound and sight of small waves breaking on the black shore lend a pacific note to a Pacific Ocean. The curve of the small beach is complete and runs away under a small grove of coconut palms, some of which are already heavily laden with rich orange-yellow nuts. The breeze plays with the palm fronds and causes the abundant growth of sedges to not their heads. Behind, the 2800 foot sierra of the heights of Santa

Cruz Island are overtopped by a layer of strato-cumulus clouds. The air temperature hovers around 24°C. All in all, it is a beautiful temperate afternoon, typical of the combination of conditions that is expected during the cool season in the archipelago. These islands have the distinction of being the coolest place at sea level on the equator in all its 24,000 mile circumference. Having just returned from an English heat wave, I find it refreshing to be in the eastern Pacific under the equatorial sun. So many seasons have passed thus, the accumulation of which have over the millenia, in conjunction with the annual interplay with the tropical warm season, given the Galápagos Archipelago a unique and incomparable climate, flora and fauna and a certain mysterious charm which, like the mythical phenomena of the Straits of Messina, can almost be an irresistible allurements.

The uniqueness and apparent stability of the Galápagos fauna and flora has as its witness a year-round tourist trade and a rich portrayal in books and magazines. Read on, but be aware that wild circumstances may have governed even fleeting moments of this earth's miniscule biosphere; that fleeting moments governed the fate of heavy somnolent grazer but also plucked with grace and threw to the future, a widening, dazzling future, small feathered organisms. Our eyes feast on this world which surrounds us, but are our senses showing the slow pacific changes of so many epochs and eras or do we observe the delicate survivors of drama, catastrophe, and possibility? I sit at peace, but the mind is charged with questions. Galápagos has now shown another face which challenges us mentally and physically. The following pages are a personal record of an exceptional year in Galápagos without historical precedence. A year more valuable to the student of Galápagos than many a year of tranquil coexistence. This is the year of El Niño 1982-83.

With no forewarning the event began. Perhaps

we should have been more suspicious. My own records of sea surface temperatures showed 25°C back in July 1982 around the southern island of Hood (Española) where we should expect 19-20°C. Perhaps we should have taken more notice of 65% abandonment of albatross eggs in that year. We may note that although mass dissertations are not uncommon with this species, the available data from the Punta Suárez breeding area shows that reproduction was poor or nil in the Niño years of 1965, 1969, 1972 and low in the pre-Niño years of 1967-68 and 1970-71 (Harris, 1973). Perhaps we should have been warned by the lack of garúa, that fine rain so very typical of the cool season (June-December) in Galápagos. However, by the end of the year much attention was being paid to the situation and at long last, in February 1983, the official voice of the Climate Analysis Center in the United States admitted that the weather was way off beam.

Although rains started to fall in October and November 1982, really heavy rains came later, the first major one in mid-December. People began to realize that, for as long as they could remember, nobody had been building houses that were waterproof! For the next seven months the heavy tropical rainstorms cleansed and watered the earth and rocks as though in compensation for their failure to do so during the last century or so. In the village of Puerto Ayora on Santa Cruz, a total of 130 inches fell, in contrast to a yearly total of less than 10 inches in other years. The record is unprecedented.

The elevated sea level, the increase of ocean temperature, with further heating from the Panamá Bight area produced a cycle of rain which was amazing. The sight of tropical storms out in the open ocean was hard to describe, for these were storms of the ocean itself. The high temperature of the water allowed quick saturation of the unstable

lower atmosphere and vertical movement produced rain. The effect was of huge mushroom-like trees growing from the sea with heights reaching many thousand feet. Any land these drifting cloud masses met augmented the precipitation by increased vertical movement. Many areas, such as Santa Fe, normally an exceptionally dry island, or the Bolívar Channel and the surrounding island masses of Isabela and Fernandina, normally described as a rain shadow area, received an unbelievable drenching this year. Pools of water, reflecting the barren landscape, collected on low blue-black lavas, giving life to patient, long dormant seeds.

But not just rain. The towering cumulus clouds billowed even higher and in the unstable atmosphere were charged with enigmatic electricity. Lightning storms are unusual in the equatorial eastern Pacific, because of the generally low temperature of the ocean waters. The period of May 16-26 includes what was later referred to as the "Noche del Rayo" of "Night of the Flash". From my diary:

16-17 Very heavy rains all night, lightning.

17 Rain in evening. Lightning bolt struck village. Electricity to house cut off by falling palm tree at 9 pm. At 9:31, a shattering noise and vivid blue flash filled the room and at the same moment candles which were on the table were extinguished. This was especially interesting as there was virtually no wind at this time. Also, at this moment I felt an electrical shock pass through my body. At the time I thought this to be possibly a subjective reaction, but the next day it was reinforced by several other people within several hundred yards who also had felt nature's power.

18-19 Showers. Winds weak, SW-S

22 Rained all day and at night till 12:30 am. Freshwater streams flooding onto beach. Lightning and thunder. Huge waterfall over cliff behind village. Cactus snapped off like twigs.

23 Warm day. No rain, but cumulus building

24 Heavy rain for 4 hours.

26 Heavy rain in evening.

This period, although outstanding in my memory, was not untypical of the climate pattern during many months.

The rain fell and fell and fell. Even on July 10, 1983, which was a few days before the rains finally ceased, I read from my journal: "Heavy rain in night (these heavy rains might be anywhere up to 8-9 inches at one time), still going on at 10 am. July 11: Winds up to Force 6 or may be 7, SE. Seems rains heaviest so far - streams rushing down beach at Stone House-landslide at Media Luna." Yet I note also, "How beautiful to see frigate birds stationary in the gale, yet with their primaries trembling in the high velocity winds! They are the wind personified. Murphy (1936) says their distribution can be related to the traditional tracks of revolving storms."

The rains very early caused a shambles to develop on Santa Cruz Island. I again refer to a report from my journal recorded after we had been out on a cruise, returning to Puerto Ayora on December 18th.

"Heavy rains on Santa Cruz have caused considerable damage in Bellavista (a village at 600 feet altitude), doors broken gardens ruined, floors flooded - great cuts formed with boulder-strewn bottoms - banana plants strewn across road where flash flooding has stripped soil to bedrock. Reports say road broken in 21 places on north side of island - closed for 3 weeks if no more rain.

With all this chaos, I also remarked, "Highlands very pretty with wetness. Plants with poor vascular systems enjoy their springtime whilst trees are asphyxiated with flooded roots."

With the extremely high humidity and concomitant rainfall, mould showed its primitive face. Mould on one's boots, mould on one's books. Refrigeration became vital for food preservation, but then frequent power failures due to the village's rain-soaked electrical system tended to reduce the value of technology. It became necessary to be absolutely interested in the rainfall and its effects in order not to despair after the nth time of sweeping the water from our floor. I found, from a human point of view, a fascination in following the idea of the limits of mental and physical tolerance. Galápagos has always been a land of harsh subsistence. The low rainfall has perhaps saved the islands from being over-exploited. Even today in some years it is obligatory to transport brackish water to the farms in the highlands for the survival of the cattle there. Yet, with the arrival of the rains, we found just the opposite. The thin topsoil was removed. The cattle stood on small hillocks whilst all around, the swirling waters busied themselves with gravity's force, taking with them the very essence of the vegetation's future! How cold are the poles, how hot the deserts, how wet the oceans. What a very small habitat is left to man! How much he needs to care for it!

On the 7th of May, I was in Bellavista talking with Alf Kastdalen, who, very sadly, was killed a few weeks later by electric shock. He related that in 1939 (which seems to have been the last major Niño year to bring heavy rains to Galápagos) the river beds were filled 14 times; this year they had run 30, but he pointed out that the *Miconia robinsoniana* habitat on top of the island had been largely damaged by fires and cattle grazing and the sponge-like nature of the surface of the ground had been altered over the years. Also the development of farming had caused a build-up of hard pan which aided surface run-off. A journey to the top of the island revealed wide swath-like areas where surface run-off had occurred through the low, grassy summit areas.

A journey was also made at this time to the El Chato area of the Giant Tortoise Reserve on Santa Cruz. A report from Linda Cayot, who was undertaking a long-term study of vegetation-tortoise interactions, showed that the tortoises had become nervous of the rushing waters which swept through their homelands and had headed to the drier coastal areas (see article by Cayot, this volume). It was extremely humid, the trails deep in red mud. The tortoises, all except three or four who persisted throughout the year, had indeed gone. In their place, sheets of water - running water - a changed view, but almost charming and alluring. Pink and green *Azolla* ferns covered tranquil ponds, leaving curious-shaped dark patches of still water with perfect reflections of *Hippomane mancinella* trees, giving evidence of the love of these trees for damp places. Only the bow wave of a passing red-billed endemic pintail duck disturbed the smooth surface of ponds. The trails, now hard to find, for no tourist had visited the area for many a month, wandered their hidden ways with no tortoise to identify them. The tall Galápagos sunflowers, *Scalesia pedunculata*, looked unhealthy, their pithy trunks unable to cope with the seas around them (see article by Hamann, this volume).

Alf Kastdalen had reported to me earlier that the *Scalesias* did not do well in wet years.

It is a change in frequencies, not so much a total destruction, for the finches, those ever curious, enigmatic birds, have bred rapidly, some pairs producing a number of broods. We saw three woodpecker finches at the same location. On the island of Daphne Major, nearly 2000 young were banded by scientists this year. When one considers that in 1981-82 the 60 nests which were started on Daphne were abandoned for lack of food, the dramatic switch is astonishing. The rains not only bring vegetation and therefore, seeds, but also an abundance of insect life, the necessary protein-rich food for the nestlings (see article by Grant and Grant, this volume).

The walk out from the tortoise Reserve was exhausting. While passing through the elephant grass, which was introduced as a pasture plant and grows to 9 feet or so, the sensation was claustrophobic and stifling and one rushed through to escape. And on the other side? A stream to wade through - how refreshing, how marvelous to stand in, to allow one's hands to play in the moving aqueous medium. But this stream was also a sign of the times. For years and years no brook travelled this way. The elephant grass, I should add, was a favorite residence of a tiny yellow insect named *Wasmannia auropunctata*, the little fire ant. They were down your neck in no time. The sensation was bearable, but not to be encouraged. These animals have been introduced and apparently the wet conditions have been to their liking but also caused them to move up into the vegetation. Whereas their advance into new habitat has in the past been measured in tens of yards, this year it may be a mile! (see article by Lubin, this volume). These ants are a menace to many indigenous arthropod species. Over the top of the trail, we sat a while, but only a while, for the orange-yellow

leaves are in fact green leaves with a coating of fire ants. But at the same moment, a female vermillion flycatcher perched on the brim of my companion's hat. Well, some things do not change.

There was a fascination to watch the water falling over the graben edge against a backdrop of *Jasminocereus*, the endemic columnar cactus, and to contemplate that here in the typically arid coastline it was so incongruous. Never could such a type of vegetation have evolved under these present conditions and perhaps, we were observing a phenomenon which was indeed a rare event, one for which few organisms were prepared. We have no records to make a judgment. However, time and events past had left their mark on these islands. I had seen the water-worn canyon to the west of Punta Comorant, the rounded rocks at the head of the trail at Espumilla beach, with the flamingo lagoon at the base of a 45 foot drop, and the arching overhang at Tagus Cove, where carved names and dates reach back to 1836, a year after the passing of the HMS Beagle with Darwin aboard. I had wondered at what distant time the waters had thundered. Now it seems more clear that these events have occurred at unspecified intervals, that they have been mere episodes in the steady progress of evolutionary processes. And yet it is important to stop and think. Perhaps these events, however short temporally, have had profound importance in the arrival of organisms and for the rapid development of genetic variation and the source of strong selection pressures. The thought of giant tortoises spreading from island to island within the archipelago has always seemed a mystery; now, no imagination is required to visualize a hapless, or lucky, animal swept down a river bed and out to sea. El Niño may also have helped bring about the rapid destruction of tortoise populations, since the rivers rushing to shore, open up highways through the vegetation that countless tortoises have utilized in their migrations to and from the nesting grounds,

but as well may have permitted human visitors of the 18th and 19th centuries easy access to the highlands and the slow, lumbering sweet flesh there.

On the beach at South James Bay, I examined a barnacle-encrusted tree, cast onto the beach with roots intact. Within the tangled seekers of water were stones and soil, a tiny haven for seeds, even insects - a graphic reality from the pages of Carlquist's (1965) *Island Life*. A few yards away, the bodies of two sea snakes (*Pelamis platurus*) lay, one a mere skeleton, but the other still alive, scaled in dazzling black and yellow. This one I placed into the sea and it was a great pleasure to see it set off backwards, a behavior of which I had read but not seen. Although these animals do not survive to breed here, the efficacy of the ocean currents as transporters of all that may lie within their compass is borne witness to as these animals are passive travelers in the surface currents.

Still it rained. Throughout the spring of 1983 it was as if a green snow had fallen over the land. Three plants, *Ipomoea triloba* (morning glory), *Merremia aegyptica* and that robust vine, *Stictocardia tiliifolia*, all members of the efficient climbing family, the Convolvulaceae, will be remembered for taking full advantage of the rains. Soon, many areas had the aspect of green undulating hillocks, as cactus, shrub, and tree were submerged beneath the encroaching tide of verdure. Not only did the cactus disappear, but in many locations, and I recall the small island of Champion especially, it began to look like a battle field where huge, ancient *Opuntia megasperma* crashed to the ground, scattering pads like a host of hedgehogs down the slopes. Overbalanced from the engorgement of water or roots rotten with saturation, they succumbed to the times (see article by Hamann, this volume).

Hood Island, whose inhabitants give such rich

evidence of the bounty of the seas in other years, now lay quiet and brooding under heavy rain clouds and fickle winds. On Christmas Day I had seen the last of the albatross chicks begging desperately for food from an adult bird, whilst both sat deep in rich green vegetation. There was no food, the cupboards of the ocean were bare. A stronger contrast between plenty and poverty would be difficult to find. The deep layer of warm water, with origins to the north and west, which was now bathing the islands was, by December, beginning to have its effects. By the end of January the sea temperature at Hood was 28°C, up to 10°C warmer than inter-Niño years. Whether temperature alone, the changes of salinity and the stability of the water layers, or the depressed thermocline, or a complex combination were responsible I do not know, but the consequences were disastrous (for further information concerning oceanographic changes in Galápagos during El Niño, see article by Kogelschatz et al., this volume). Not only did it appear that the vital fish stocks, such as herring and anchovy, had all but disappeared, but the algae, certain species of which are vital food for the marine iguanas, were dying. Whilst terrestrial iguanas paced their new-found paradise with fattened limbs and tails and could afford for once to view the sunsets with equanimity, a glazed and empty stare had settled within the blunted heads of their marine counterparts (see article by Laurie, this volume). On the 29th of January, six blue-footed boobies were all that remained on Hood Island of a colony that formerly numbered in the thousands; no breeding was occurring. At that time it was interesting that the masked boobies were still raising young. I saw a regurgitated flying fish, but no courtship display. The downy young were naked on their necks apparently from incessant scratching for the whole area was seething with mosquitos (*Aedes* sp.) which took advantage of their ability to breed in salt ponds created by exceptionally high tides. There were dead gulls on the beaches. These were

young Franklin's gulls (also see article by Sosa, this volume), for the beautiful, bouyant, endemic swallow-tailed gulls had by now deserted the islands, having no doubt moved south, following perhaps, old hunting grounds and cold water. These gulls were not to be seen again, except sporadically until July. Mosquitos drove us from this saddened place.

We who could choose did not return to Hood Island for several months. In the interval, the sea produced fine eating fish: yellow-finned tuna (*Thunnus albacorus*), we caught one weighing 52 pounds; wahoo (*Acanthocybium solandri*); and dorado (*Coryphaena hippurus*), members of the Scombridae and Coryphaenidae - wide-ranging pelagic predators of tropical and subtropical seas. But where were the famous Galápagos bacalao (*Mycteroperca olfax*)? Warps of fishing boats lay idly in fixed form on the bollards and sun-baked decks lay bereft of naked, calloused feet.

The unique geographical position of the archipelago is one of its fascinations. At the juncture of warm and cold currents, it is able to support penguin and red-footed booby, fur seal and tropic bird, but only a constant climatic give-and-take allows such strangers to coexist. An extreme in either direction would soon give a strong bias as to which lives and which dies.

And so it is in May that we returned to Hood, where the sea temperature was 28.5°C. The albatrosses, true to their annual cycle, returned in late March from their southern feeding grounds, even though oceanographic conditions had not changed. Nesting was a disaster. A combination of factors - lack of food, thick ground cover, torrential rain, mosquitos - rendered their life on earth, hell. Eggs were lost in the vegetation or flooded by water.

Soon, masses of birds were to be seen out in the ocean, forming the albatross rafts, perhaps uncertain and returning to their world of sea and air, forsaking the land until better times. However, for them, with low annual adult mortality, a few years of poor breeding are not of major concern (see article by Rechten, this volume). The blue-foots were not to be seen on Hood Island and now it became the turn of the masked boobies to desert their cliff-edge homes to seek the ever more scarce food.

Yet on April 6, 1983, from Tower Island, I read from my dairy: "Frigates exceptional - almost every male displaying - a blaze of red across the green *Cryptocarpus* bushes." So one species at least has time to spend in temptation of the female sex. Is it that these aerial lords survive by kleptoparasitism, augmenting their food sources by the labour of others or is it their catholic tastes that give them the advantage? Great frigates from Christmas Island are recorded feeding on flying fish, sea basses, dorado, surgeonfish, small mackerel, pufferfish, porcupinefish, and triggerfish (Schreiber and Hensley, 1976).

Yet those downy young, offspring of arboreal red-footed boobies, give evidence of perhaps an even more successful species of booby. In contrast to the failure of their congeners, the red-foots took full advantage of the slow growth rate of their single offspring and slowly week by week, month by month, brought them to the stage of flight over crystal blue water. Week by week brown eyes turn to grey as morsel after morsel of scarce flying fish is wearily brought homeward after long searches over the great arc of the heating ocean.

Iguanas lay at my feet. Who was alive and who was dead? The rocks offshore looked black and uninviting. The trance-like stare as metabolism diminished was disturbing and the transition from life

to death was unbelievably gentle and indiscernable. Living arms and heads still embraced and utilized a softer pillow than hard basaltic rock. Bodies who in another year, braved whitefoam to harvest riches from the sea, but now lay slowly crumbling back to earth.

What else has suffered beneath the interface of gas and liquid? For many organisms the changes in the ocean have been too severe and wide mortality has taken place. From January onward, the corals especially hermatypic forms started to die off and by May, when I dived with Gary Robinson off Champion Island near Floreana, a calculation of about 70-90% mortality was noted. In the clear waters the rounded white coral heads had the appearance of a battlefield with the bodies of the vanquished anemic from loss of blood. And over all was growing a soft, green filamentous alga. Gone were the sharks and larger fish. Interestingly enough, reports from northern Chile stated that the fishing industry was doing better than ever and an abundance of sharks, turtles, and medusae were arriving off the coast. We swam to the experimental stations Gary had set up to study the growth of black coral only to find them, too, dead and the filamentous alga encroaching on the cement blocks on which the black coral had been placed. The already established black coral had been succumbing to these alga. To the east of Corona del Diablo, a degraded old cinder cone off the north coast of Floreana, the beautifully delicate free-living fungus corals had also lost the apparently vital zooxanthellae, which normally give them a brownish or greenish coloration. From a distance the structure of the fragile skeleton, with its radiating curving ridges, was clearly visible, but a close view revealed that the animals still persisted with life. The polyp with short stubby tentacles, now transparent, looked dangerously vulnerable (also see article by Robinson, this volume).

By now also, the broad, bleached white skulls and skeletons of the fur seals, *Arctocephalus galapagoensis* were becoming common. They appeared simply to have run out of food and for months their wasting bodies could be seen at their rocky homes with the sun making more harsh the relief of the protruding ribs and vertebrae (see article by Limberger, this volume). What also had become of the green endemic sea urchin and the *Heliaster* starfishes? Why would the playful bottle-nose dolphins stop but for a few seconds in the bow wave where before they had amused themselves for 20 or 30 minutes?

In July I dived in Tagus Cove on the western coast of Isabela. The once bejeweled wall of invertebrate life was a monotonous sheet of filamentous alga. The only points of color were a few *Tubastrea* a beautiful yellow-orange ahermatypic coral. At 75 feet we hit the thermocline which had not been there 3 months earlier. At the surface the temperature was 28.8°C, below the thermocline 21.6°C! Perhaps at long last the times were changing.

I left Galápagos on July 12 and returned on September 6. In that period of time, sea surface water temperatures fell dramatically and in mid-September, they were between 21°C and 24°C in the bay of Puerto Ayora. The rain had stopped and garúa had set in. The evenings were cool and fresh.

Two weeks ago I walked down to the Tortoise Reserve with Linda Cayot to view the outcome. Light drizzle led us down through the farms, the ground caked and cracked. The hiking times in and out were the old times, about 1½ hours. One walked almost as in a dream. Had this year really been? Of course the evidence was there, but more fascinating than the evidence was the recovery. The fast flowing streams were gone, but the stream beds were still there. Already, however, the banks were falling in, weedy plants were stretching tendrils and stolens

across the bare rocks, and the pale dead mats of alga, which had formed in the more permanent streams, no longer green, were still oriented in the direction in which their fronds had been wafted by the rushing waters. The upper and lower ponds at the Caseta still contained water. The upper, its northern end filled with alluvium, was now covered with bright green grass. At its southern end - yes, the wheel evidently turns, the tortoises were back! We counted seven where none had been seen for months. How quickly they reacted! They were mostly males, though we did find a male and a female together, perhaps they had been mating. Dead *Scalesia* trees were all around, but many survived. And everywhere was the evidence of a drying world. The once rampant *Stictocardia* now with skeletal leaves was a victim of explosive insect larval production and a shortage of water. Two or three smooth-billed anis chortled and chattered their incongruous voices in the Galápagos ecosystem. All around, the numbers of finches were amazing, especially the warbler finches, whose delicate morphology and grace of movement is always a fascination when compared to the slow-moving vegetarian finch.

So we walked out of the reserve, questioning whether all the spectacular changes had really ended and perhaps, as always, judging the time scale on the ephemeral human life span and coming to many wrong conclusions. But as one turns and looks back down the trail to the distant hazy coast and the sea beyond, one longs to know more.

A survey of penguins and flightless cormorants showed dramatic population declines (Valle, this volume).

Population Census				
Cormorants	Year	1977	1980	1983
	No.	683	802	409
Penguins	Year	1971	1980	1983
	No.	1931	1720	398

Although the cormorants are making a rapid recovery utilizing the dessicated bodies of marine iguanas as nesting material on Punta Espinosa, the penguins seem slow to respond, although some breeding is occurring. One is made acutely aware of the delicate balance that allows these animals to exist and the importance of a watchful eye on any changes which may occur within their habitat.

How many evolutionary bottle necks have been before, pushing populations to extremes, and who survives the squeeze? How many population explosions have given rapid thrust to genetic variability? We do not know. But the Galápagos ecosystem may be a reflection of such dramatic times.

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PARTE III

EFFECTOS EN LA VIDA MARINA

EFFECTS ON MARINE LIFE

INFLUENCE OF THE 1982-83 EL NIÑO ON
GALAPAGOS MARINE LIFE

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Summary

Observations of the biological consequences of the 1982-83 El Niño on numerous elements of the Galápagos marine flora and fauna are provided. Widespread bleaching and mortality of hermatypic corals, especially *Pocillopora damicornis*, *Pavona clavus*, and *Porites lobata*, was recorded at several island locations. Gorgonians, black corals, barnacles, giant scallops, and ahermatypic corals also evidenced increased mortality. Marked declines in abundance were noted for many endemic fishes and in sessile invertebrate communities typical of the normally productive western region of the Galápagos Archipelago. On the other hand, several species showed increased abundance or increased their range through the islands during El Niño. Most notable were fish species also known to occur in the Indo-Pacific and Panamic regions, e.g. moorish idols, filefishes, some species of labrids and scarids. High levels of juvenile recruitment were recorded for ghost crabs and portunid crabs.

Strong events such as the 1982-83 El Niño may favor transport and establishment of marine organisms from comparatively warmer tropical regions than the Galápagos and may be a significant factor contributing to the great diversity of marine forms found in these islands. The extensive coral mortality

observed during the 1982-83 El Niño may have far reaching consequences on local Galápagos marine communities long after oceanographic conditions normalize.

Resumen

Observaciones de las consecuencias biológicas de El Niño 1982-83 en elementos numerosos de la flora y fauna marina de las Galápagos son suministradas. Los corales hermatípicos, *Pocillopora damicornis*, *Pavona clavus* y *Porites lobata* demostraron blanqueo y mortalidad en muchos sitios de archipiélago. Gorgonios, corales negros, cirrópodos, conchas gigantes y corales ahermatípicos también mostraron mortalidad elevada. Declinaciones en abundancia fueron notadas en muchas especies de peces endémicos y en comunidades de invertebrados sésiles típicos de la región productiva del oeste de las Islas Galápagos. Por otra parte, varias especies mostraron abundancias aumentada o aumentaron sus rangos en el archipiélago durante El Niño. Peces conocidos en las regiones Indo-Pacíficas y Panameñas (ídolo de moro, pez de lima, lábridos y peces loro) fueron los ejemplos mas notables. Altos niveles de reclutamiento juvenil fueron registrados de cangrejos fantasmas y jaibas.

Fuertes eventos como lo de Niño 1982-83 pueden favorecer el transporte y establecimiento de organismos marinos de orígenes tropicales como del Indo-Pacífico y pueden contribuir a la diversidad de la fauna y flora marina encontrada en las Islas Galápagos. La mortalidad extensa de corales observada durante El Niño puede tener consecuencias de mucho alcance en las comunidades marinas locales, mucho después que las condiciones oceanográficas se normalicen.

INTRODUCTION

At irregular intervals of 3-7 years, a warming event known as the El Niño phenomenon occurs in the normally productive region of the eastern tropical Pacific Ocean (Trenberth, 1976). A thickening layer of warm, low salinity water depresses the depth of the thermocline, thereby preventing the upwelling of cool, nutrient rich water (Barber & Chavez, 1983; Rasmusson, 1984). Reduced availability of nutrients in the well-lit surface waters of the ocean leads to decreased levels of primary productivity which ultimately affects all levels of the food web. Widespread mortality of sea birds and fish is often observed. Catches of commercially important fish species such as anchovies and sardines frequently decline causing economic disasters for South American coastal nations like Ecuador and Peru (Barber & Chavez, 1983).

The 1982-83 El Niño has been labeled as perhaps the strongest event known this century (Halpern, 1983; Kerr, 1983). Some of its biological consequences have been documented. Barber & Chavez (1983) report a 20-fold decrease in phytoplankton biomass along coastal Peru during May 1983, which probably caused a reduction of anchovy stocks available to the fishery. Low food availability (fishes and cephalopods) was attributed as the cause for total reproductive failure of boobies and frigate birds at Christmas Island (Schreiber & Schreiber, 1983; 1984) and high levels of pup mortality in Galápagos fur seals (Limberger et al., 1983; also this volume). Glynn (1984) reported bleaching and mortality of several species of hermatypic corals in the eastern Pacific associated with the occurrence of El Niño conditions.

In this chapter, I will describe a wide range of changes that were observed in many elements of the Galápagos marine flora and fauna in association

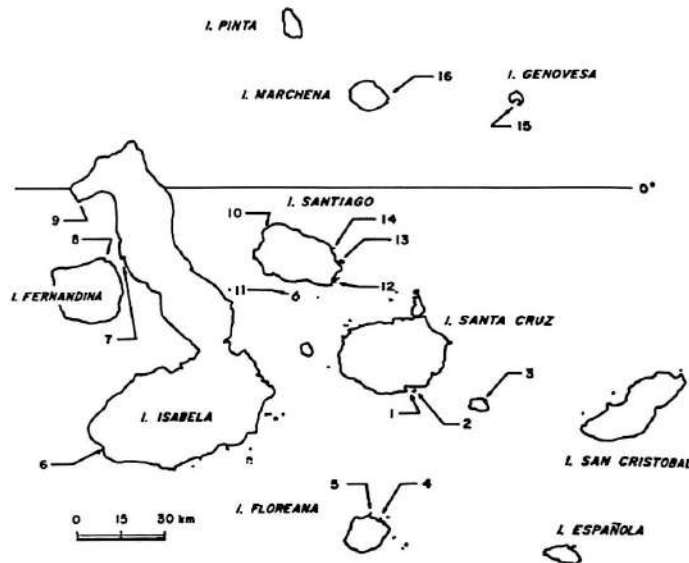


Figure 1. Study sites in the Galápagos Islands mentioned in the text and in Tables 2 & 3.

Site No.

1. Academy Bay, Santa Cruz Is.
2. Caamaño Islet, Santa Cruz Is.
3. NE Anchorage, Santa Fe Is.
4. Champion Is., near Floreana Is.
5. Onslow Reef (Devil's Crown), Floreana Is.
6. Iguana Cove, Isabela Is.
7. Tagus Cove, Isabela Is.
8. Espinosa Point, Fernandina Is.
9. Point Vicente, Isabela Is.
10. Bucanero Cove, Santiago Is.
11. West of visitor site, Rábida Is.
12. Bainbridge Rocks, Santiago Is.
13. Bartolome Is., near Santiago Is.
14. Cousin's Rock, Santiago Is.
15. Darwin Bay, Genovesa Is.
16. Espejo Point, Marchena Is.

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with the 1982-83 El Niño. It will become evident that I use 'changes' to denote a broad spectrum of responses encompassing fluctuations in abundance, mortality, incidence of disease, island-wide changes in distribution and small-scale distributional shifts in local habitats. For the most part, these changes can only be said to have occurred during El Niño. Interannual variability in population size for most Galápagos marine organisms has not been studied to any great extent with perhaps the exception of seabirds and pinnipeds. Therefore, it is difficult to ascribe a causal link between El Niño and the changes observed. However, the magnitude of many of these changes and the mortality displayed by a wide range of organisms, especially long-lived hermatypic corals and giant scallops, make it likely that El Niño conditions were involved either directly via elevated ocean temperatures, abundant rainfall, or elevated sea level, or indirectly through depressed primary productivity and its impact on the food web.

METHODS

Qualitative observations were made at several sites throughout the Galápagos Archipelago during the period of November 1982 to August 1983. These sites are indicated in Figure 1. Many of these same sites had been previously visited on several occasions during fieldwork on black coral populations in 1981 and 1982.

CHRONOLOGY

The onset of changes in Galápagos marine life to be described in more detail in later sections, did not take place simultaneously. A change in typical encrusting invertebrate communities normally present at Tagus Cove, Isabela, was noted in November

1982. In most years, relatively cool productive waters are restricted to the western region of the archipelago (17–19°C, annually) due to the influence of the upwelling Cromwell Current (Maxwell, 1974, Houvanaghel, 1978). Many of the sessile invertebrates to be found encrusting the vertical rock walls of Tagus Cove are strikingly reminiscent of temperate forms (tunicates, sponges, bryozoans, cup corals, sea pens). During November 1982, water temperature to a depth of a least 33 meters was measured at a uniform 27°C. The absence of encrusting mats of compound tunicates and large colonies of the calcareous tube-building serpulid worm (*Salmacina* sp.) was most striking. Patches of the sponge, *Cliona* were less numerous than previously. Numerous dolphinfish, *Coryphaena hippurus*, and sierras, *Scomberomorus sierra*, were observed within Tagus Cove itself, something that I had not previously witnessed.

In December 1981 and March 1982, blue-footed boobies (*Sula nebouxii*) were actively nesting on Point Vicente on the northern tip of Isabela. In December 1982, no birds were nesting and the colony which formerly numbered in the hundreds or perhaps over a thousand birds was greatly reduced in size.

The first heavy rainstorm was recorded on December 6, when over five inches of rain fell (see articles by Grant & Grant; Cayot, this volume). Several low lying areas on the grounds of the Charles Darwin Research Station filled with water overnight. One of these lava depressions was situated not more than 10 yards from the high intertidal zone. Fairy shrimp (Anostraca) and clam shrimp (Conchostraca) soon hatched out in this pond and became very abundant within a few weeks. One could not help but wonder how long the desiccation resistant eggs of these organisms had lain dormant, waiting for the next major Niño rains to fill the pool.

Three weeks during January 1983 were spent conducting fieldwork at the island of Champion near Floreana. Sharks were rarely seen during diving excursions as were amberjacks (*Seriola* sp.). No young sea lions joined us on our dives to playfully steal data boards or tug at our transect lines. The colony of sea lions that formerly numbered in the hundreds in July 1982, had declined to less than 50 individuals; several emaciated and apparently abandoned pups were seen as well as numerous individuals observed with symptoms of sea lion pox (Figure 2).

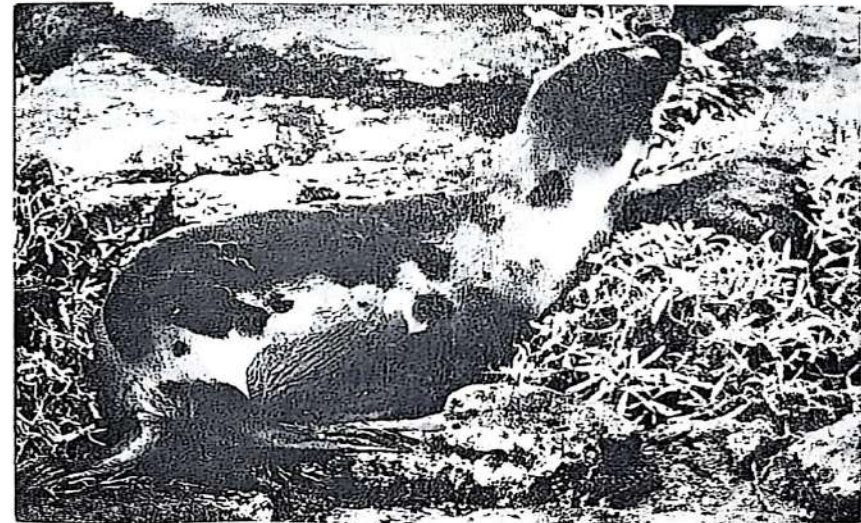


Figure 2. A 1–2 year old Galápagos sea lion with characteristic pox sores. The incidence of this disease appeared to be greater during El Niño conditions. Sea lions may have been more susceptible to this disease due to stress caused by elevated air and sea temperatures and by the scarcity of food.

Our most vivid recollections of our fieldwork at Champion and Floreana concern the weather we experienced during January. On two occasions, heavy rains flooded our camp and produced rushing streams that ran all day and discolored the surface waters with sediment to perhaps a mile out to sea. On January 6, large ocean swell arriving from the NW, contrary to the normal direction of S-SE, within hours transported a small sandy beach (approx 50 meters x 6 meters wide), 200 meters toward the next point of land to the east, leaving behind a beach composed of boulders and cobble. The sand gradually migrated back to its former location over the next few days as swell from the normal S-SE direction returned. On January 14, a 2-2.5 m swell from the NW again transformed the beach and literally 'tore-up' the coastline. Large subtidal boulders were overturned and tumbled up the beach face. Large heads of massive corals (*Pavona* and *Porites*) were dislodged from shallow subtidal areas and deposited above the high tide line. *Pocillopora* corals were torn loose and ground to beach rubble along with many sea urchins (*Eucidaris*) and starfish (*Nidorellia*) also cast ashore. The shoreline vegetation of *Maytenus* and *Cryptocarpus* was beaten back several meters by the onslaught of breaking waves and rolling rocks. During this period, we observed waves breaking onto a large (>6 m tall) tree cactus (*Opuntia megasperma*) on Champion Is. Later, in June 1983, this cactus was not present even as a remnant - a victim of exposure to salt water. Perhaps because these large NW swells coincided with the occurrence of spring tides and the rise in sea level observed during El Niño (Wyrski, this volume) they exerted a greater impact on the shoreline than they would have in a normal year.

None of our observations made at Champion during January led us to suspect that more pervasive changes in marine life were going to occur. Corals appeared normal as did many other subtidal organisms. However

by mid-February, corals began bleaching in Academy Bay, Santa Cruz Is. Barnacles became empty shells and formerly conspicuous subtidal algae looked unhealthy, especially *Blossevillea galapagensis*. Numbers of the endemic green sea urchin, *Lytechinus semituberculatus*, were few compared to former levels. At first we assumed that the great amount of FW runoff from the heavy rains were responsible for these events. However, accounts of dead and dying corals were often reported by visitors to other island sites. Visits made by myself to many of these sites during March, April, May and July 1983 confirmed that island wide perturbations were taking place. Bleached hermatypic corals were observed throughout the archipelago at depths to 30 meters, far below the influence of local FW runoff. The condition of corals worsened as the months progressed bleaching more and becoming colonized by opportunistic filamentous algae (Figure 3). In most places, subtidal rocks and corals to about 20 m depth took on a monotonous carpet of brown filamentous algae, principally *Giffordia* and *Enteromorpha* sp. Other curious declines or shifts in distribution of marine species were noted.

By August 1983, oceanographic conditions were apparently normalizing (Kogelschatz et al., this volume) but many marine organisms reduced to low population levels during El Niño have remained rare into April 1984 (J. Grove, G. Merlen, pers. comm.).

CORAL BLEACHING AND MORTALITY

All hermatypic coral colonies appeared to have normal pigment coloration in January 1983, but by mid-February, corals in Academy Bay were bleached. Extensive bleaching of the *Pocillopora* reef at Onslow Reef (Devil's Crown) was reported in February (T. De Roi Moore, pers. comm.). Observations in Academy Bay, near the research station and at Isla

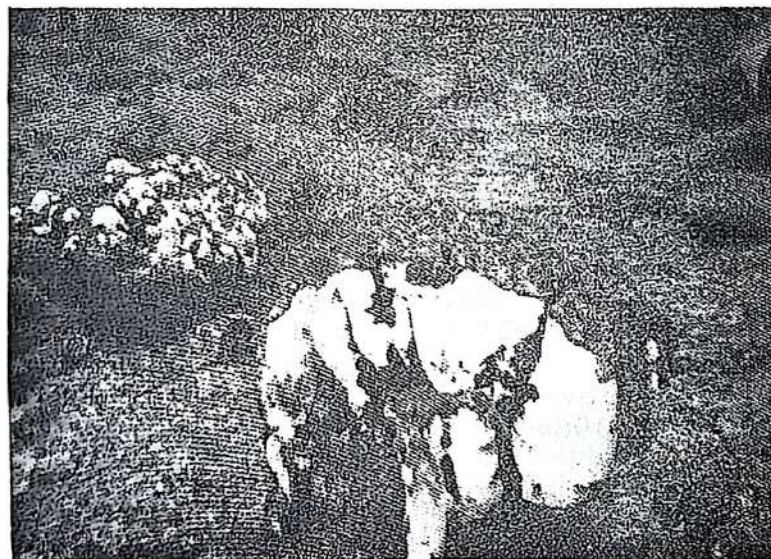
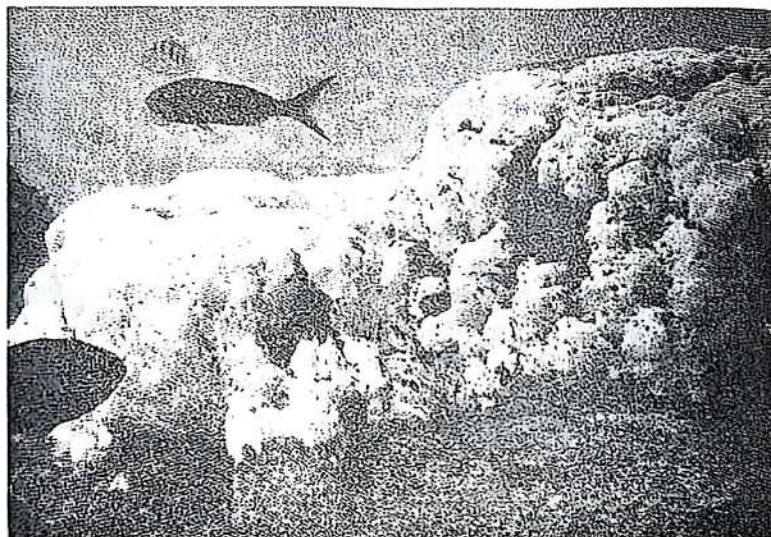


Figure 3. (Above) Bleached colony of *Porites lobata* photographed in 4 meters at Champion Is. in June 1983. (Below) Bleached colonies of *Pavona clavus* (foreground) and *Porites lobata* photographed at Beagle Rocks, near Santiago Is., in May 1983. Depth was approximately 5 meters. Filamentous algae had colonized much of the upper surfaces of both colonies. This same alga was present on much of the surrounding rocky reef.

Caamaño revealed that all the major species of hermatypic corals were involved. Coral heads of *Pocillopora*, *Porites lobata*, and *Pavona clavus* were 100% affected within the shallow semi-enclosed area of Academy Bay (nearest to CDRS). In addition to these species, *Pavona gigantea* and *Psammocora stellata* also showed bleaching at the Caamaño site but to a lesser extent. Typically, bleaching was confined to the top surfaces of colonies with side retaining pigment and normal appearance of polyps. Bleaching was most pronounced in shallow water and became less in deeper water. Curiously, coral colonies situated on the shadow-sides of rock ledges appeared unaffected even in shallow depths.

Several bleached specimens of *Pocillopora*, *Pavona* and *Porites* collected from Caamaño and returned to the research station failed to take-up the bone stain, Alizarin red, indicating that no active calcification was occurring in the bleached corals (Glynn, 1984). Zooxanthellae were not present and bleached *Pocillopora* corals produced no mucous nor were polyps easily discernible.

In March 1983, bleaching heads of massive corals were observed to 20 m depth near Espejo point, Marchena Is. Some colonies possessed a yellowish hue or were streaked. Again, *Pavona gigantea* appeared the least susceptible to bleaching.

By the later part of April 1983, many corals were being colonized by filamentous algae, particularly on their upper surfaces (Figure 3). This algal turf slowly invaded bleached areas over the next few months. Colonies in shallow water were almost 100% monopolized by the algal turf. That bleached corals were not immediately colonized by opportunistic algae in February 1983, indicates that coral tissue was present though polyps were not expanded when corals were observed at night. It is assumed that as time progressed, coral tissue,

reduced to a thin film, began to die and slough, exposing new calcareous substrate to algal colonizers

Coral development is not very extensive in the Galápagos Islands despite its equatorial location due to the relatively cool waters that bathe the islands. However, the coral formations at Isla Champion and Onslow Reef are significant and have been the subject of previous study (Wellington, 1975; Glynn et al., 1979; Glynn & Wellington, 1984). At Isla Champion, massive coral colonies, some reaching a height of 2 meters, are present on a shelf extending westward of the island to 15-20 meters depth. Onslow Reef is a shallow patch reef of *Pocillopora* with scattered heads of *Pavona clavus* and *Porites* sp. On the periphery at slightly greater depths, *Pavona* corals and scattered *Psammocora* are common.

The condition of hermatypic corals at Isla Champion and Onslow Reef was surveyed on May 24-25, 1983. Results are summarized in Table 1. All colonies of *Pocillopora* were dead and colonized by a dense algal turf. At Onslow reef, the actual areal coverage of *Pocillopora* framework was reduced compared to the coverage reported in 1975. Strong waves and tidal currents apparently scoured out the central portion of the reef.

Previous study demonstrated that *Eucidaris* urchins feed on live *Pocillopora* corals (Glynn et al. 1979). Calculations of urchin grazing rates, urchin densities, coral coverage and coral production indicated that urchins could potentially limit the lateral extension of the patch reef at Onslow. In 1983, no significant mortality of *Eucidaris* was noted and cursory examinations of gut contents indicated that urchins were still eroding coral framework as they grazed on the luxuriant algae. Because of the persisting coral framework, small *Eucidaris* possess a refuge from potential fish predators such as

Table 1. Condition of hermatypic corals on Isla Champion and Onslow Reef, Galápagos. Censused on 24-25 May 1983. Observations of corals were made over a depth range of 1-25 meters at Isla Champion; 1-16 meters at Onslow Reef.

Coral Species	Appearance of Affected Colonies	I. Champion		Onslow Reef	
		% Affected	N	% Affected	N
<u><i>Pocillopora damicornis</i></u>	Dead, overgrown by algae	100	47	100	36
<u><i>Porites lobata</i></u>	Bleached, algal invasion	68.1		100	25
	Bleached, algal invasion, some tissue present on sides and undersurfaces	31.9	72		
<u><i>Pavona clavus</i></u>	Bleached, algal invasion	100	60	100	12
<u><i>Pavona gigantea</i></u>	Bleached, alive	44.7		77.4	
	Bleached, some algal invasion some normal pigmentation on sides and undersurfaces	52.6	38		31
	Normal	2.7		22.6	
<u><i>Psammocora stellata</i></u> ²	Bleached, alive	50	10	20	5
	Normal	50		80	
<u><i>Cycloseris mexicana</i></u>	Bleached, alive	---	---	100	18

² *Psammocora stellata* unaffected below 12 meters at Onslow Reef

Bodianus diplotaenia, *Oplegnathus insignae*, and *Sufflamen verres*. If urchin density remains high over the next few years and a refuge for urchins persists in the coral framework, it is conceivable that recruitment of new colonies of *Pocillopora* may not be able to keep pace with foraging pressure exerted by sea urchins. The El Niño disturbance may have set in motion the means by which a coral patch reef may be converted into a coral barrens. Future studies of the Onslow Reef would provide significant insights into the role of El Niño disturbances in Galápagos coral reef communities.

East of Onslow Reef, on a sandy bottom in 15 m depth is a dense patch of leaf corals, *Cycloseris mexicana* (Glynn & Wellington, 1984). These hermatypic corals are large solitary polyps lying loose on the bottom. The bed is quite large and has been stable in size and location since its discovery in the early 70's. These corals, too, were bleached in May and July 1983, though no mortality was observed. Polyp tissues were absolutely transparent and devoid of zooxanthellae.

At Isla Champion, massive *Porites lobata* and *Pavona clavus* corals showed extensive bleaching and some colonies were almost entirely colonized by algae. No colonies of *P. clavus* had areas of normal pigmentation; *Porites lobata* colonies were dead on their upper surfaces but still alive on the sides or in shadowed areas. As in other areas, *Pavona gigantea* and *Psammocora stellata* demonstrated the least amount of bleaching.

In summary, *Pocillopora* coral reefs in shallow water suffered high mortality followed by *Pavona clavus* and *Porites lobata*. *Pavona gigantea* and *Psammocora stellata* were less susceptible to bleaching and algal colonization. *Cycloseris mexicana* showed 100% bleaching but no obvious mortality.

Into December 1983, corals have not shown recovery (G. Merlen, pers. comm.). At Wenmann Is. (2°N, 91°W) at least 90% of the corals were affected by bleaching and algal invasion down to a depth of 30 m. However, by January and February 1984, corals began to recover normal pigmentation, especially *Cycloseris* and thin laminar forms of *Pavona*. New coral growth was extending over dead areas. G. Merlen reports however, that many individual colonies of the massive or columnar forms of *Porites* and *Pavona* appear to be dead at Champion and J. Grove reports toppling of some dead colonies. The size of some of these coral heads (>1 m) considered with known growth rates for *Pavona* of 6-12 mm per year (Glynn & Wellington, 1984) suggests that they were at least 3/4 of a century old.

Coral bleaching and death were not confined to the Galápagos Islands. Glynn (1984) was the first to report the occurrence of this unusual event in the Gulf of Chiriqui on the Pacific coast of Panamá. There, a hydrocoral, *Millepora*, showed high mortality as did some reefs of *Pocillopora*. Bleaching of corals near Panamá took place contemporaneously to that observed in the Galápagos (Jan-Mar, 1983).

Causes for this major coral disturbance which involved much of the eastern tropical Pacific are as yet unknown. While sea surface temperature was higher and salinity lower than normal in Galápagos (Kogelschatz et al., this volume), conditions were not unusual in Panamá (Glynn, 1984). Goreau (1964) has shown that FW runoff may induce coral bleaching as can sedimentation (Johannes, 1975; Marszalek, 1981). Such factors may have contributed to coral bleaching in shallow Galápagos waters, but bleaching of corals off Panamá coincided with the dry season when FW runoff and sedimentation are minimal (Glynn, 1984). Jokiel & Coles (1977) demonstrated that prolonged exposure to elevated water temperatures

induced the loss of photosynthetic pigment and increased mortality in the Hawaiian corals, *P. damicornis*, *Montipora verrucosa* and *Fungia scutaria*. A following study (Coles & Jokiel, 1978) showed that high light intensities aggravated survival ability of *M. verrucosa* to exposure to elevated temperature and reduced salinity. It is interesting to note that during El Niño in Galápagos, it was observed that individual coral colonies situated in shadows and shaded portions of colonies did not undergo bleaching as was typical of colonies in light-exposed areas. The prolonged El Niño conditions of 1982-83 with sea temperatures 27-30.5°C from November 1982 to July 1983, reduced salinities and nutrient regimes, and high light intensities penetrating to greater depths due to water clarity apparently triggered the loss of coral symbionts through emigration or expulsion from coral tissue. Consequently, corals grew very little and many died.

Glynn & Wellington (1984) studied skeleton banding patterns in *Pavona clavus* and *P. gigantea* specimens collected from the Galápagos. Generally, greater growth rates were observed in warmer years, although Galápagos corals show large variation in growth rates between sites in the archipelago which may be influenced by local effects such as differences in temperature, cloud cover, sedimentation and food abundance. Coral skeletons with their banding patterns, have been utilized as recorders of past ecological conditions in the area surrounding the reef and have been used to reconstruct past sea temperatures, earlier El Niños and to examine the concentration of radiocarbons of anthropogenic origin in seawater (Druffel, 1981; Glynn & Wellington, 1984). The value of corals as recorders becomes problematic because it is now evident that extremely strong climatic perturbations such as the 1982-83 El Niño, which had global effects on weather, may only appear as a small, dense growth band or not at all, or perhaps, as a void where coral has died

and been subsequently overgrown by recolonizing coral tissue in following years.

The death of large, fairly old massive coral heads corroborates evidence that the 1982-83 El Niño may indeed have been the strongest event this century.

MORTALITY

In addition to the major Galápagos species of hermatypic corals, numerous other kinds of marine organisms showed obvious signs of increased mortality during the 1982-83 El Niño (Table 2). By virtue of their hard skeletons, a permanent account of these die-offs were observable.

The gorgonians, *Muricea* sp., *Pacifigorgia douglasi* and *P. darwini* and the black corals, *Antipathes panamensis* and *A. galapagensis* displayed similar responses to the 1982-83 warming event. All appeared healthy in January 1983 but by mid-March significant numbers of dead or partially dead colonies were observed at many island sites. These cnidarians sloughed tissue beginning at their distal tips which then progressed downward toward the colony base. The exposed internal skeleton was quickly colonized by filamentous algae. It was difficult to ascertain if colonizing algae were hastening this process or merely quick to settle upon newly exposed substrate. Gorgonians and black corals in shallow depths (<20 m) were most affected while colonies below this depth remained relatively free of any algal growth. Similar to the hermatypic corals previously described, colonies of *Muricea* or *Antipathes* that were situated under ledges or in shadows showed no tissue loss whatsoever. I observed several such colonies in 3 m depth at Tagus Cove, Isabela. *Pacifigorgia* was affected despite their apparent preference for attachment sites between and under

Table 2. Galápagos marine organisms (other than hermatypic corals) displaying increased mortality during the 1982-83 El Niño.

Species or group of organisms	Observation Sites (see Fig. 1 legend)	Remarks
Black Corals		
<u>Antipathes panamensis</u>	7,12,14	Sloughing of tissue from distal tips of branches Overgrowth by filamentous brown algae
<u>Antipathes galapagensis</u>	4,7	Sloughing of tissue from distal tips of branches Overgrowth by filamentous brown algae
	7	High juvenile recruitment
Ahermatypic Corals		
<u>Tubastrea tagusensis</u>	7,9,14	100% Mortality (1-30 m)
Gorgonians		
<u>Pacificigorgia darwini</u>	2,4,5,7	Sloughing of tissue
<u>P. douglasi</u>	9,10,14	Overgrowth by filamentous algae (1-20 m depths most affected)
<u>Muricea spp.</u>	2,7,8,9	Sloughing of tissue Overgrowth by filamentous brown algae
Molluscs		
<u>Lyropecten magnificens</u>	7,9	Presence of shells, no live individuals encountered

Table 2. Continued

Species or group of organisms	Observation Sites	Remarks
Barnacles		
<u>Megabalanus galapaganus</u>	1,2,10,14	Presence of empty tests, no live individuals
<u>Tetraclita squamosa</u> <u>milleporosa</u>	1,2,10,14	Presence of empty tests, no live individuals
Seabirds		
<u>Nannopterum harrisi</u>		Reduced numbers (see article by Valle)
<u>Spheniscus mendiculus</u>		Reduced numbers (see article by Valle) Greater movement of individuals between islands
Reptiles		
<u>Amblyrhynchus cristatus</u>		High incidence of mortality (see article by Laurie)
Pinnipeds		
<u>Arctocephalus galapagoensis</u>		High incidence of juvenile mortality, starvation observed in adults (see article by Limberger)
<u>Zalophus californianus</u> <u>wollenbecki</u>	3,4	Incidence of pox disease, starvation and abandonment of juveniles Fewer individuals in colonies

boulders in surge channels. At Champion and several sites near Academy Bay, Santa Cruz Is., all colonies of this species were dead by July, 1983.

Some of the dead colonies of *Muricea* measured at least 30 cm in height. If growth rates of this Galápagos gorgonian are comparable to species of *Muricea* found in Californian waters, then 18-20 years of age for dying gorgonians is not an unreasonable estimate (Grigg, 1974).

The endemic black coral, *Antipathes galapagensis* while showing significant adult mortality in shallow, light-exposed areas also demonstrated high juvenile recruitment at study sites at Tagus Cove and Isla Caamaño. Ten cinder blocks (15 x 15 x 30 cm) which were placed in depths of 10, 20, and 30 m depths at Tagus Cove in November 1981 showed no recruitment of any black corals over the following 1½ years. However, juvenile corals measuring 1-4 cm height were noted on deep rock ledges beneath overhangs in May 1983. I counted 22 juveniles on one cinder block which equates to 488 individuals per m². Evidently, warm water conditions favored the reproduction or successful recruitment of this species. The population of black corals under study at this site displayed a size frequency distribution of adult colonies which suggested temporally sporadic recruitment. It may be that successful recruitment of juveniles of *A. galapagensis* is greater during warm events such as El Niño. Adult population densities of black corals in Tagus Cove range from 0.5 to 1.4 colonies per m², so few of the numerous settling juveniles observed in 1983 will probably survive (Robinson, 1982).

On dives made during March 1983, no living colonies of the endemic popcorn coral, *Tubastrea tagusensis* could be found at Tagus Cove and Point Vicente down to 30 meters depth. Formerly, these corals accounted for 10-30% of the live coverage

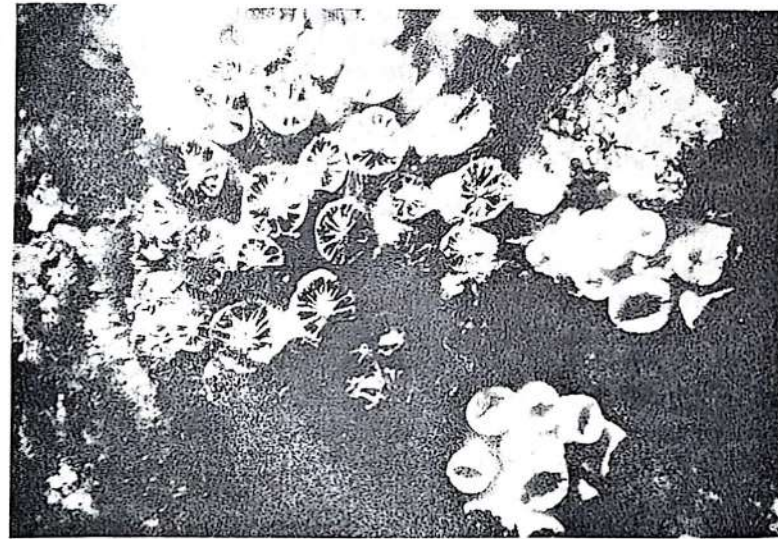


Figure 4. Photograph of a dead colony of *Tubastrea tagusensis* taken at 15-20 meters depth at Tagus Cove, March 1983. The two smaller colonies at the right are living *T. coccinea* with their polyps withdrawn. This later species showed no obvious mortality during El Niño.

on rocky ledges and underhangs below 15-20 meters (Glynn & Wellington, 1984). These corals were one of the high points for tourists on night diving excursions because of their brilliant splashes of color when the polyps are expanded at night. In March 1983 all that remained were skeletons (Figure 4). Its congener, *Tubastrea coccinea*, which is widely distributed in the eastern Pacific remained healthy throughout El Niño conditions. It does not seem likely that these two species depend on markedly different food resources that may have been differentially affected by Niño conditions. Polyps are similar in size and the two species occupy similar habitats. It may be that the two species possess differing physiological tolerances to variations in

temperature, salinity, and ambient light intensity. All of these factors taken together may have exceeded the lethal limits of *T. tagusensis* leading to their virtual extinction from the areas surveyed. No recolonization has yet been observed (G. Merlen, pers. comm.) in April 1984. This species may still persist in deeper water but recruitment rates may be so low that their reestablishment in former areas may take years. Meanwhile, dead coral substrates are being colonized by algae, tunicates and sponges.

The giant scallop, *Lyropecten magnificens*, which ranges along the Pacific coast of South America and is commonly found in the waters of the Galápagos Archipelago below 25 meters, also showed evidence of significant mortality. Three individuals were present along an established transect line in 30 meters at Tagus Cove and their positions had been noted in June and November 1982. They were still present in their exact locations in May 1983 but only as shells. Numerous empty *Lyropecten* shells had been encountered at Point Vicente in March 1983 and it is believed that a general die-off of this species occurred sometime in February 1983.

Barnacle mortality was observed as early as February at most island sites. This quickly approached the level of 100% death for both *Tetracita squamosa milleporosa* and *Megabalanus galapaganus* by March 1983. Mortality may have been influenced by heavy rains and FW runoff during low tides and by the low primary and secondary productivity during Niño conditions.

The negative influence of the 1982-83 El Niño on populations of Galápagos fur seals, *Arctocephalus galapagoensis*, and marine iguanas, *Amblyrhynchus cristatus*, is treated elsewhere in this volume in articles by D. Limberger and A. Laurie, respectively.

DECLINES IN ABUNDANCE

Numerous species were less frequently encountered during 1982-83 than in former years (Table 3). In some cases, the decline in abundance was dramatic.

Baleen whales essentially disappeared from the archipelago whereas in normal years they are frequently observed in island upwelling areas, especially around the southwestern and northwestern areas of I. Isabela. Bottlenose dolphins (*Tursiops truncatus*) which frequently accompany boats as they travel between islands, only rarely did so during 1982-83 and usually only a few individuals appeared. Sharks were noticeably absent and sea lion colonies appeared deserted compared to densities in previous years. It is believed that these marine organisms migrated from near-shore Galápagos waters in search of fish prey. Adult sea lions apparently abandoned pups and stayed out to sea in search of food. Galápagos sea lions were reported hauled out on beaches along the coast of mainland Ecuador and one individual was reported seen in Panamá (Y. Lubin, pers. comm.). Limberger (this volume) reports that compared to previous years, female Galápagos fur seals stayed out to sea for significantly longer periods before returning to nurse pups - probably due to scarcity of prey. Consequently, many pups starved or were abandoned altogether.

Migration of adult sea lions may not have been the only reason for their observed decline. Sea lion pox disease may have been a contributing factor (Figure 2). This disease is present in all years and usually increases in incidence during the warm months (December-March). The means by which this disease is transmitted is not known. It is manifested by sores and pustules spread over the entire body and young sea lions, particularly, become paralyzed in their hind limbs with occasional forelimb involvement. Individuals severely afflicted with

Table 3. Galápagos marine organisms encountered less frequently during the later months (Mar-Jul) of El Niño.

Species or groups of organisms	Observation Sites (see Fig. 1 legend)	Remarks
Algae		
<u>Blassevillea</u>	1	Thinning haptera (February)
<u>galapagensis</u>		Completely absent by end of March 1983
<u>Sargassum</u> spp/	7,8	Absent
<u>Ulva</u> sp.	1,8	Absent
Sponges		
<u>Cliona</u> sp.	7,8,9	Absent from western islands
<u>Tethya</u> sp.	1	Absent from under intertidal boulders
<u>Haliclona</u> sp.	1	Loss of coloration, disintegration of sponge
Sea Pens		
<u>Ptilosarcus</u> sp.	7	Complete absence. Also other unidentified species
Polychaetes		
<u>Salmacina</u> sp.	6,7	Absence of colonies from western islands (first noticed in November 1982)
Echinoderms		
<u>Lytechinus</u> <u>semituberculatus</u>	1,6,13	Extremely low abundance

Table 3. Continued

Species or groups of organisms	Observation Sites	Remarks
Tunicates		
<u>Astropecten</u> sp.	7	Absence from western islands
<u>Linckia</u> sp.	6,7,8,9	Absence from western islands
<u>Heliaster cumingi</u>	7,9	Absence. Possibly related to widespread mortality of barnacles, especially in intertidal
Various species		
	6,7,8,9,14	Low abundance and live coverage of subtidal rocks in western islands
Fishes		
<u>Nicolsina denticulata</u>	1,2	Low abundance due to loss of <u>Blossevillea</u> habitat
<u>Acanthemblemaria</u> <u>castroi</u>	2,3,5,6,10,14	Absent
<u>Nexilosus latifrons</u>	6,7,8,9	Few individuals, some observed with skin infections (also see article by Grove)
<u>Bodianus eclancheri</u>	7,8,9	Fewer individuals present
<u>Mycteroperca olfax</u>	3,4,5,6,7,9 10,11,12,13,14	Low abundance Migration to deeper water?
<u>Paralabrax albonaculatus</u>	7,9	Low abundance Migration to deeper water?

this disease become emaciated and starve. This author's general impression is that sea lion pox disease became much more prevalent during 1982-83. Perhaps low food availability (nutritive stress) and high ambient temperature (thermal stress) led to increased susceptibility to pox disease.

In the central islands, a brown alga, *Blossevillea galapagensis*, forms a conspicuous margin in the surge zone delimiting the low intertidal from the subtidal. In February 1983, this alga began to die back in Academy Bay, first sloughing the distal haptera. By March, all that was left of this normally luxuriant two-foot tall alga were a few strands of withered haptera arising from weakened holdfasts. By April, nothing remained.

In similar fashion, *Sargassum* spp. in the western archipelago disappeared. This material is utilized extensively by flightless cormorants to construct their nests on the rocky shoreline. Faced with a shortage of this resource, cormorants employed dead gorgonians, twigs of *Cryptocarpus* and late in the year, the skeletal remains of marine iguanas (see Figure 7 in article by Limberger).

Many resident reef fishes became noticeably less abundant as El Niño continued. Grove (this volume) points out that a large proportion of fishes that qualitatively evidenced declines were island endemics or possessed a geographical range extending into the cooler Peruvian-Chilean zoological province.

El Niño greatly affected the islands' artesanal fishery. This is a seasonal fishery based on demersal serranids (groupers) which are prepared as a dry salted product. Generally, the fishing season extends from October to April. Nearly all the Galápagos product is consumed in traditional dishes prepared throughout Ecuador during the Holy Week (Easter). In the early months, as El Niño developed,

artesanal fishermen continued to report good catches in the western archipelago during October and November. Fishing effort remained high in December, but catches of the most important species, "bacalao" (*Mycteroperca olfax*), "camotillo" (*Paralabrax albonotatus*), and "vieja" (*Semicossyphus darwini*) declined. It is presumed that these species migrated to deeper, cooler waters during El Niño conditions. In diving surveys, bacalao and camotillo were few in relatively shallow reef areas normally populated with them. Fish rapidly returned to these areas in August when El Niño conditions subsided.

Demersal fish species which fishermen did manage to catch proved difficult to dry to the finished product. Normally, brine-soaked fish meat is distributed over coastal lava rocks heated by the sun to dry. This is usually accomplished during the fishing trip with the product stored in the vessel's hold until port is reached. Because of the persistent rains and high humidity, fishermen encountered problems in finding opportunity to dry fish during any particular fishing trip and in achieving a sufficiently dry product that would not spoil in the vessel's hold. The result was an inferior product and lower profits for fishermen. Actual fish production statistics from the Galápagos were not yet available to compare 1982-83 year's effort with previous years by the time of publication of this volume.

Change in abundance of three other fish species deserves elaboration. The toothed parrot fish, *Nicholsina denticulata*, commonly inhabits the *Blossevillea galapagensis* beds at the border of the intertidal zone using the alga as forage and cover. As these beds disappeared in February, so did the population of *Nicholsina*. Some individuals may have migrated to other habitats and perhaps others fell victim to predators.

In my recollection, perhaps one of the most dramatic see-saws in abundance when comparing pre- and post-El Niño periods was that of the endemic chaenopsid barnacle blenny *Acanthemblemaria castroi*. Subtidal boulders on reefs exposed to wave surge are often encrusted with *Megabalanus galapaganus*, the empty tests of which are occupied by *Acanthemblemaria* and less frequently by the blenny, *Hypsoblennius brevipinnis*. By the end of February 1983, the virtual extinction of *Acanthemblemaria* from all former areas was noted. Concerted searches for this species throughout the islands at dive sites indicated in Figure 1 did not record one single individual. Abundances of *Hypsoblennius* on the other hand appeared normal. Both J. Grove and G. Merlen report that the barnacle chaenopsid has still not been sighted in Galápagos as of April 1984.

What may have been responsible for this remarkable decline? Virtually no studies of *Acanthemblemaria castroi* have been undertaken other than an investigation of mating behavior (Wirtz, 1981). This blenny was often seen peering upward into the water column from its barnacle refuge. The fish would dart out and upward to snatch zooplankton or drifting invertebrates swept from the reef by currents and waves before quickly returning to their barnacle abode. The low productivity of the 1982-83 El Niño probably resulted in low zooplankton abundance which may have led to local extinction of *Acanthemblemaria*. *Hypsoblennius brevipinnis* may have a more catholic diet which includes grazing upon filamentous algae which were very abundant during El Niño.

Damselfish form conspicuous elements of the tropical reef fish fauna. Only one species in Galápagos showed obvious signs of decline - *Nexilosus latifrons*, the rusty damselfish. This is a cool water species confined to the western archipelago and also ranging along the coast of Peru and Chile.

Nexilosus is a resident reef fish which forages upon the abundant invertebrate cover typical of the western islands of Isabela and Fernandina. Populations gradually declined as El Niño continued presumably for lack of food and fungal skin infections which were noted in several of the remaining individuals at Tagus Cove in June 1983. Grove (this volume) reports localized extinctions of this species.

Lastly, the endemic sea urchin, *Lytechinus semi-tuberculatus* seems to have suffered during the 1982-83 El Niño. Normally found in great abundance in shallow subtidal cobble and boulder fields (such as the embayment near CDRS), this species has also virtually disappeared and not been seen again as of April 1984 (G. Merlen, pers. comm.).

INCREASES IN ABUNDANCE AND INTER-ISLAND DISTRIBUTION

In harmonious balance to the decline of marine organisms previously described, many species were favored by El Niño conditions and displayed greater abundances or increased their ranges through the archipelago (Table 4). Such species typically share affinities to tropical faunas of the western Pacific or the Panamic region. Pelagic fish predators (scombrids and dolphin fish) were commonly captured on trolling lines much to the relief of tourist boat operators who depended on catching fresh fish to serve their passengers and found the normally reliable bacalao scarce. Grove (this volume) mentions other fish species that became common in the western archipelago, particularly moorish idols, *Zanclus*; filefish, *Aleutera*; and parrotfish, *Scarus* (especially *S. rubroviolaceus*).

The yellow-bellied sea snake, *Pelamis platurus* in most years is only an occasional visitor to the Galápagos Islands, being carried to the islands during the southerly transport of water from north of the equator during the warm months (December

Table 4. Marine organisms displaying greater frequency or increasing interisland distribution in the Galápagos during El Niño.

Species or group of organisms	Observation Sites (see Fig. 1 legend)	Remarks
Crustaceans		
<u>Ocypode gaudichaudii</u>	1,5	High juvenile recruitment
<u>Cronius ruber</u>	1	High recruitment of juveniles in saltwater lagoons
Fishes		
<u>Aluetera scripta</u>	1,7,14	Frequently observed
<u>Acanthurus glaucopareius</u>	1,2,7,14	Wider distribution in islands
<u>Coryphaena hippurus</u>	6,7	Frequently caught on trolling lines throughout the archipelago
Scombrids	6,7	Frequently caught throughout the archipelago
Reptiles		
<u>Pelamis platurus</u>	1,3,10,12	Frequently reported by guides and boat operators

to February). Between the months of February and April, more specimens of sea snakes were observed or collected in the Galápagos Islands than make up the entire collection of sea snakes at the research station covering roughly 17 years. Since these organisms are distributed by surface currents, their presence in the islands is strong support for the transport of warm, low salinity water from the Panamá region.

The settlement of juvenile crustaceans of two species was remarkable. *Ocypode quadrichaudii*, the ghost crab, became very abundant on many Galápagos sandy beaches where there had been very few previously. They settled in great numbers and their burrowing and sand foraging activities impressively plowed up the sandy beaches at Punta Cormorant on Floreana Island and Tortuga Bay on Santa Cruz Island. The other species showing high recruitment of juveniles was the portunid, *Cronius* sp. Larval or juvenile crabs were apparently carried into many salt water lagoons during the maximum elevation in sea levels in January and March (see article by Wyrski, this volume). Months later, Galápagos residents on many islands were able to capitalize on the ubiquitous swimming crabs which were greatly prized as food (Tupiza, this volume).

Mulletts drawn to areas where the island aquifer system mixed with the sea, were caught in great abundance by gill-net fishermen. In addition, with all the fresh water streams running on many islands, *Macrobrachium* shrimp became the focus for capture by enterprising Galápagos residents. Cruz (this volume) describes multitudes of these shrimp occupying a stream that ran from his farm, 1 to 2 miles inland, to the sea. In most years, this stream is merely a dry creek bed. As El Niño rains began to cease, shrimp concentrated in drying pools and were easily captured.

SHIFT IN LOCAL HABITAT

With the increase in sea level associated with El Niño conditions, high tides breached the berm of beaches and in some cases cut a channel between back lagoons and the sea (Tupiza, this volume). In some cases this greatly altered the lagoon ecosystem and may have indirectly led to the abandonment of these lagoons by wading birds such as flamingos and stilts.

In Academy Bay, two species of fiddler crabs are present, one of which (*Uca galapagensis*) occupies a distinct high tide band in muddy sediment areas around mangroves. As the sea level increased during El Niño, the band of fiddler crabs migrated shoreward and soon were seen to be extensively burrowing a low section of the dirt road stretching between the town of Puerto Ayora and CDRS. Stronger waves than normal also carried and deposited sandy sediments higher up in the intertidal zone. The second species of fiddler crab, *U. helleri*, which generally prefers coarser sandy sediments in the mid-intertidal for its burrows, also migrated shoreward and in some places, populations of the two fiddler crab species became mixed.

CONCLUSIONS

The changes that occurred in certain species of Galápagos marine life contemporaneously with the progressions of the 1982-83 El Niño were remarkable. Doubtless, there were other, perhaps subtle, changes which someone else would have found equally worthy of mention. In the foregoing sections I have tried to document some of the impacts of Niño conditions on Galápagos marine life that I found impressive, to illustrate the range of responses observed, and in a few cases, to indicate how man's relationship to this remote archipelago was affected. It is

hoped that interest in Galápagos marine ecosystems will be stimulated by this effort and that endeavors to quantify interactions between populations of marine species and their aquatic environment in the Galápagos be considered by researchers.

Oceanographic variability and unpredictable rainfall are hallmarks of the Galápagos Island group. Frequently, this variability is depicted as a seasonal 'sea-saw' between a cool, high salinity South Equatorial Current system and a warm, low salinity North Equatorial Current system. Each system affects the islands to differing degrees during the progression of the seasons and is one factor contributing to the high habitat diversity and species diversity characteristic of the Galápagos (Wellington, 1983). During the 1982-83 El Niño, warm, low salinity, nutrient depleted water invaded the archipelago and produced a uniform tropical condition. Nutrient-rich water, restricted below the thermocline which itself was depressed to greater depths by the blanket of warm tropical water, was removed from the range of upwelling waters around Galápagos Islands. Consequently, a number of marine species dependent on highly productive upwelling regions in the Galápagos Islands, by necessity were forced to migrate to more productive areas, curtail reproductive activities or other unnecessary expenditures of energy, or failing these alternatives, starve and possibly perish. The intimate relationship between reproductive success in seabird colonies and ocean productivity is well-known and has been used as an indirect means to measure productivity of upwelling ecosystems (Barber & Chavez, 1983). In Galápagos, reproductive failure, mortality and migration were reported for nearly all vertebrate species dependent on the marine environment for sustenance (see articles by Grove, Laurie, Limberger, Rechten, and Valle, this volume).

The extensive bleaching and mortality of hermatypic corals throughout the eastern Pacific (Glynn, 1984) was one of the more pervasive impacts recorded of the 1982-83 El Niño. In Galápagos, some sites experienced complete loss of entire populations of coral species such as that of *Pocillopora* at Onslow Reef. Loss of this species will have impacts on the structure of coral-associated marine communities in Galápagos long after Niño conditions have subsided.

Some of the observations presented here and those by Grove (this volume) on Galápagos fishes describe declines for a number of endemic species. It seems somewhat paradoxical that certain endemic species which originally evolved in the Galápagos marine ecosystem should demonstrate a high degree of sensitivity to oceanographic perturbations such as the Niño phenomenon. Conversely, these dramatic declines serve to illustrate the strength of the 1982-83 event. The value of utilizing entirely aquatic marine species in addition to reproductive success; failure of seabird or pinniped colonies for assessing the magnitude of an El Niño event are suggested by the observations presented here. In Galápagos, hermatypic corals and the endemics, *Acanthemblemaria castroi* (barnacle chaenopsid), *Lytechinus semituberculatus* (green sea urchin) and *Tubastrea tagusensis* (popcorn coral) are likely candidates for indicator species. It is unfortunate that baseline information on the abundance and distribution of these species was not acquired in the years prior to 1982-83 against which to truly quantify the magnitude of the event. Nevertheless, death of long-lived organisms, such as massive corals or piñón trees, *Jatropha curcas*, planted by original colonists on Floreana (E. Cruz, this volume) supports statements that a Niño event of similar intensity has not been witnessed in the last 100 years.

Lastly, there is a tendency to connote El Niño phenomenon with negative impacts. Certainly man's ability to deal with the unusual amounts of rainfall, altered distributions of marine resources, and other Niño-induced perturbations are frustrated. The 1982-83 El Niño will probably be long remembered for its global impacts on weather which resulted in catastrophic losses in damage to structures, crops and the toll of human lives. But there is another, perhaps esoteric dimension to El Niño. Rarely occurring events of the intensity of the 1982-83 phenomenon may push species to the brink of extinction in their ability to survive the adverse conditions. Once these conditions ameliorate, small founding populations may persist in isolated areas within the Galápagos Islands, as an example. Isolation, mutation, and genetic drift may operate on these small founding populations making possible the evolution of new species. Thus, rare El Niño's by severely depleting populations, may set the stage for the production of new species.

El Niño and its influence on the Galápagos Islands is important in another respect. Strong easterly transport of surface waters from the Indo-Pacific region and more commonly, southerly transport from the Panamic region during development of Niño conditions may facilitate the transport of adults or dispersal stages of marine species as yet not indigenous to the Galápagos. The prolonged conditions of the 1982-83 may favor the recruitment and successful establishment of species of tropical affinities which may ultimately become permanent constituents of Galápagos marine communities and add to their diversity.

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INFLUENCE OF THE 1982-1983 EL NIÑO EVENT UPON THE ICHTHYOFAUNA OF THE GALAPAGOS ARCHIPELAGO

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Summary

Data collected during the 1982-83 El Niño event in the Galápagos Islands revealed one species of fish which has gone unrecorded since the warm water conditions abated. There was a decrease in the population size of no less than 17 species of fishes, 50% of which are endemic and none are of west Pacific origin. On the other hand, as a result of El Niño 1982-83, there was an increase in the population size, and/or expansion of range, of 19 species. These included no endemic forms and 42% which have zoogeographic affinities with the tropical west Pacific. 4 species not previously known from the archipelago are reported. 39 species classified in 25 different families are tabulated in this report.

Resumen

La información colectada en las Galápagos durante el evento de El Niño 1982-83 reveló que una especie de pez no ha sido registrada desde que cesaron las condiciones cálidas del agua. Hubo un decrecimiento en el tamaño de las poblaciones de no menos de 17 especies de peces, 50% de las cuales son endémicas y ninguna es originaria del Pacífico oeste. Por otro lado, como resultado de El Niño 1982-83, hubo un incremento en el tamaño poblacional

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y/o expansión del rango de 19 especies. Estas no incluyen a formas endémicas y 42% de ellas tienen afinidades zoogeográficas con el Pacífico tropical del oeste. Se reportan 4 especies que no han sido registradas antes en el archipiélago. En este trabajo se tabulan 39 especies que están clasificadas en 25 familias diferentes.

The Galápagos marine environment has been classified as sub-tropical (Ekman, 1953), however, during the 1982-83 El Niño event sea surface temperatures exceeded 30°C. This is a preliminary report on the alterations that occurred in the fish populations of the Galápagos Archipelago as a result of extreme El Niño conditions.

Distributions of the Galápagos fishes were monitored over a five year period, prior to and including the 1982-83 El Niño event. During this period, observations, collections and underwater photographs were used to document regular, seasonal variations in species composition, relative abundance and insular distribution. Specimens collected were placed in the collections of the Instituto Nacional de Pesca (INP), Guayaquil, Ecuador, and the Los Angeles County Museum of Natural History (LACM), Los Angeles, California. All photographs are cataloged in the archives at the LACM.

Monitoring of Galápagos fishes was conducted at the following localities:

1. Española Island: Punta Suárez - embayment on the north side of the point.
2. Onslow Reef (Devil's Crown): Inside the crater and around the external perimeter on east and north side.

3. Santa María Island (Floreana): Punta Cormorant - surrounding the point.
4. Santa Cruz Island: Academy Bay, Tortuga Bay and along the north shore of Caamaño Islet.
5. Plazas Islands: Along all shores, primarily in the channel between the islands and adjacent to the east shore of Santa Cruz Is.
6. Bartolomé Island: Sullivan Bay.
7. San Salvador Island (James): South James Bay and Espumilla Beach, North James Bay.
8. Isabela Island: Tagus Cove and along the west coast northward for 2 km, also Cape Berkeley.
9. Fernandina Island: Punta Espinosa - region surrounding the northern and northeastern-most portions of the point.
10. Tower Island (Genovesa): Darwin Bay - adjacent to the beach in the northwest corner of the bay.

RESULTS AND DISCUSSION

Vertical and latitudinal migrations and distribution of the fishes of the Galápagos Islands are influenced by a variety of oceanographic parameters. Rosenblatt and Walker (1963) suggested that the shifting of warm and cool ocean currents through the islands may result in changes in the composition of the ichthyofauna. The extent of this variation has not been documented.

Generally, the oceanographic setting of the Galápagos Archipelago is influenced by the Peru

Current System and the Southeast Tradewinds. From August through October the tradewinds blow to a maximum velocity of 18-20 knots resulting in the upwelling of cool (20-24°C), saline waters (>35‰). The tradewinds subside around January and warmer (25-28°C), lower salinity waters (as low as 33.5‰) invade the islands from the north. These, and other changes in water conditions are accompanied by variations in species composition and distribution of the Galápagos fishes.

Seasonal variations in the populations of Galápagos fishes are best known for those species of commercial value. The dorado, *Coryphaena hippurus*, for example, is rare or absent among the islands throughout most of the year, however, they increase in number with rising sea surface temperatures. In this species, the migration is latitudinal, as the dorado come into the islands with the warm waters from the north. In other species, seasonal movements are vertical, in accordance with the movement of the thermocline. From January to March, Galápagos fishermen must fish in deeper, cooler waters to catch preferred species such as bacalao, *Mycteroperca olfax*, vieja, *Semicossyphus darwini* and camotillo, *Paralabrax albomaculatus*.

To a certain extent, the variations in the zoogeography and ecology of the Galápagos fishes which occurred during the 1982-83 El Niño event may be considered a prolonged amplification of the typical seasonal variations with more dramatic and long-term effects. The impact of this El Niño event was not restricted however, to those species which exhibit annual variation in distribution within the islands. Endemic species and those species with zoogeographic affinities with the ichthyofauna of Peru and Chile, were most dramatically reduced in number (Table 1). Few of these species are likely to have migrated into deeper water or away from the island system and are, therefore, believed to have

Table 1. Species observed less frequently during the 1982-83 El Niño. Water depths $\leq$ 50 m. E = Endemic; PAN = Panamic, generally from Peru northward to the Gulf of California; WP = Tropical West Pacific; C = Circumtropical; PC = Peru and Chile; na = not applicable at this identification level.

Species	Family	Distribution
<i>Xenocys jessiae</i>	Haemulidae	E
<i>Xenichthys agassizi</i>	Haemulidae	E
<i>Azurina eupalama</i> ¹	Pomacentridae	E
<i>Labrisomus dentriticus</i>	Labrisomidae	E
<i>Labrisomus jenkinsi</i>	Labrisomidae	E
<i>Acanthemblemaria castroii</i>	Chaenopsidae	E
<i>Girella fremenvillei</i>	Kyphosidae	E
<i>Paralabrax albomaculatus</i>	Serranidae	E
<i>Chromis atrilobata</i>	Pomacentridae	PAN
<i>Nexilosus latifrons</i>	Pomacentridae	PC
<i>Semicossyphus darwini</i>	Labridae	PC
<i>Nicholsina denticulata</i>	Scaridae	PAN
<i>Mycteroperca olfax</i>	Serranidae	E
<i>Sphyrna lewini</i>	Sphyrnidae	C
<i>Aetobatus narinari</i>	Myliobatidae	C
<i>Carcharhinus</i> spp.	Carcharinidae	na
<i>Urotrygon</i> sp.	Dasyatidae	na

¹ Not recorded in Galápagos since November 1982.

suffered a high rate of mortality.

For example, the rusty damselfish, *Nexilosus latifrons* and the endemic tube blenny, *Acanthemblemaria castroii* were not recorded in the islands from August 1983 until June of 1984. *Labrisomus dentriticus* and *L. jenkinsi*, members of the family Labrisomidae (previously Clinidae) also disappeared during the 1982-83 El Niño and showed no signs of

Table 2. Species observed in greater frequency during the 1982-83 El Niño. Water depths ≤ 50 m. E = Endemic; PAN = Panamic, generally from Peru northward to the Gulf of California; WP = Tropical West Pacific; C = Circumtropical; PC = Peru and Chile; na = not applicable at this identification level.

Species	Family	Distribution
<u>Acanthocybium solandri</u>	Scombridae	WP/PAN
<u>Acanthurus xanthopterus</u>	Acanthuridae	WP/PAN
<u>Acanthurus glaucopareius</u>	Acanthuridae	WP/PAN
<u>Kuhlia mugil</u> ²	Kuhliidae	WP/PAN
<u>Alutera scripta</u>	Monacanthidae	WP/PAN
<u>Zanclus canescens</u>	Zanclidae	WP/PAN
<u>Hemipteronotus taeniorus</u>	Labridae	WP/PAN
<u>Thalassoma lutescens</u>	Labridae	WP/PAN
<u>Pseudojulis notospilus</u>	Labridae	PAN
<u>Scarus rubroviolaceus</u>	Scaridae	PAN
<u>Fistularia commersonii</u>	Fistularidae	PAN
<u>Aulostomus chinensis</u>	Aulostomidae	PAN
<u>Scomberomorus sierra</u>	Scombridae	PAN
<u>Stegastes acapulcoensis</u>	Pomacentridae	PAN
<u>Kyphosus analogus</u>	Kyphosidae	PAN
<u>Kyphosus elegans</u>	Kyphosidae	PAN
<u>Strongylura exilis</u>	Belonidae	PAN
<u>Coryphaena hippurus</u>	Coryphaenidae	C
<u>Caranx spp.</u>	Carangidae	na

²This species was previously confused with Kuhlia taeniura.

reappearing until May 1984. The two plankton feeding damselfish (Pomacentridae) in the Galápagos are *Chromis atrilobata* and *Azurina eupalama*; both of these species were affected negatively by the El Niño. *Chromis atrilobata* is a wide ranging east Pacific species which was reduced in number, but not to the same extent as the endemic *Azurina eupalama*.

Interestingly, these two closely related species often fed in heterotypic aggregations. While the former has slowly increased in number, the later has not been recorded from the islands since the warm water event began. This may substantiate the theory that endemic species are less tolerant of extreme environmental change than more wide ranging forms.

While El Niño conditions led to decline of certain endemic and temperate forms, other tropical and sub-tropical fishes expanded their insular distribution and greatly increased in number (Table 2). The moorish idol, *Zanclus canescens*, for example, was recorded for the first time along the west shore of Isabela Island. During non-El Niño years this region of the archipelago has sea surface temperatures 2-5° cooler than the rest of the archipelago. In 1983, when temperatures became uniformly and abnormally high throughout the islands, the fishes were no longer restricted by inter-island temperature gradients. Another species which expanded its insular range and increased notably in frequency was the sunset wrasse, *Thalassoma lutescens*. Prior to El Niño 1982-83, this species was common only among the northern islands. Presently, the sunset wrasse is also a conspicuous element of the reef fish fauna in the central and southern islands of the Galápagos Archipelago.

Although El Niño may not have been the reason for the arrival of 4 species of fishes reported as new to the Galápagos (Table 3), it is clear that at least two, previously rare species, increased in number. Both the acapulco damselfish, *Stegastes acapulcoensis* and the dragon wrasse, *Hemipteronotus taeniorus* are considerably more abundant now than they were before the El Niño event.

The significance of ecological studies in the aftermath of a natural catastrophic event, in a microcosm such as Galápagos cannot be underestimated.

Table 3. Records of species not known from the Galápagos prior to 1982. PAN = Panamic, generally from Peru northward to the Gulf of California; na = not applicable at this identification level.

Species	Family	Distribution
<u>Pareques viola</u>	Sciaenidae	PAN
<u>Stethojulis bandanensis</u>	Labridae	PAN
<u>Mustelus</u> sp.	Mustelidae	na
<u>Urotrygon</u> sp.	Dasyatidae	na

Note: This list does not include fourteen new records of Galápagos fishes collected during a joint expedition of the Los Angeles County Museum of Natural History and the University of Costa Rica to the islands of Darwin (Culpepper) and Wolf (Wenmann) in May 1984.

The author is hopeful that this preliminary report will stimulate interest in the establishment of a long-term, marine biological monitoring program, in what remains one of the precious few, relatively unaltered, marine ecosystems of our water planet.

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THE EFFECTS OF THE 1982-83 EL NIÑO ON MARINE IGUANAS

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(Editors' Note)

Andrew Laurie began his studies of population dynamics of the marine iguana, *Amblyrhynchus cristatus* in 1981 and has continued these studies into 1985. The following report, extracted from his Progress Reports Nos. 3 & 4, describes the results of work on reproductive success, growth and mortality of marine iguanas during 1982-83 and 1983-84. The 1982-83 season was dominated by the El Niño event which led to massive mortality of marine iguanas throughout the archipelago, apparently as a result of change in algal flora. The effects of this unusual event extended into the following year's reproductive season.

(Nota de los Editores)

Andrew Laurie inició sus estudios de la dinámica poblacional de las iguanas marinas, *Amblyrhynchus cristatus*, en 1981 y los ha continuado hasta 1985. El siguiente artículo se deriva de los Reportes de Progreso números 3 y 4 y describe los resultados del estudio del éxito reproductivo, el crecimiento y la mortalidad de las iguanas marinas durante las épocas reproductivas de 1982-83 y 1983-84. La época 1982-83 estuvo dominada por El Niño. Se observó mortalidad elevada de las iguanas en todo el archipiélago, aparentemente como resultado del cambio en la flora de algas, fuente alimenticia de estas iguanas. Los efectos de El Niño se extendieron a 1983-84.

METHODS

Field work in 1982-83 was concentrated on Santa Fe Island from September 1982 to May 1983, with two visits to Caamaño islet and Punta Nuñez on Santa Cruz Island in September and March. Due to the massive mortality of marine iguanas observed, the coastline was regularly checked for corpses and field autopsies were performed whenever possible. Five whole body specimens and numerous organs were fixed in formalin for later examination. A major change in algal flora occurred during the 1982-83 El Niño and samples of newly colonizing species were collected together with stomach and intestine contents from dead iguanas and specimens of vomit from live, sick iguanas. Duplicate algal samples were collected in dilute formalin and sea water for later identification and in 70% alcohol for subsequent analysis for toxic effects.

Two survey trips were made to the islands of Isabela, Fernandina, Santiago, Pinta, Marchena, Tower, Plazas, and Española during May and June 1983.

The 1983-84 season's fieldwork again concentrated on the Santa Fe study site, with a survey trip to Fernandina and Isabela in late March and a few short trips to Santa Cruz, Caamaño, and Plazas in January, February, March, and April. Experiments to determine the digestibility of various species of marine algae were carried out using artificial saliva and sheep rumen fluid. Three more iguanas which died after El Niño were collected and analyzed in detail.

RESULTS

Male territoriality and mating success - 1982-83

Two colonies were observed in detail during the 1982-83 mating season which began almost three

weeks earlier than the previous year, but extended for a slightly longer period (1981-82 reproductive season, 18 December to 5 January versus 1982-83 reproductive season, 30 November to 27 December). The distribution of successful matings among the territories of the main colony was similar to the previous season, but territory holders of the most 'profitable' territories in 1981-82 (in terms of numbers of matings in any one season) were either non-territorial this season, or were not seen at all. They were replaced by males which did not hold territories in the same colony in 1981-82. Occupants of 'inferior' territories in 1981-82 largely returned to the same territories this season.

It appears, therefore, that the males who successfully defend prime territories, where they obtain 12-30 matings in a single season, may do so at such an energetic cost that they are unable to breed in successive seasons. On the other hand, those males that defend inferior territories can obtain two to five matings in successive seasons at relatively little cost in terms of fasting and energy spent on territorial defense.

Female breeding and nesting 1982-83

Results very similar to last season's confirm that all adult females do not breed every year. Of 72 adult females observed throughout the 1982-83 season, 14 were seen mated, of which 10 (71%) were later seen nesting. Whereas, of the 58 females not seen mated, only 8 (14%) were seen nesting. These data, combined with the 1981-82 data, show (using the binomial distribution, 95% confidence limits) that only between 32% and 48% of adult females breed in any one year, indicating that females normally breed only every two to three years (mean 2.5 years).

Overall, considering females seen at the nesting area, only 3 out of 50 marked females which were seen nesting in 1981-82 returned in 1982-83, and there were at least another 63 marked females nesting in 1982-83 which were not seen nesting in 1981-82. The energetic costs of nesting may indeed account for such skipping of opportunities to breed; six (9.5%) of the 63 marked females known to have nested this year were later found dead, compared with ten (<5%) recorded deaths among at least 200 marked females which were alive and in the study area during the nesting period, but were not themselves seen nesting.

El Niño and its effects

Southern Oscillation-El Niño events occur at intervals of two to ten years in the tropical Pacific Ocean and are characterized by anomalously high sea-surface temperatures, heavy rainfall, and unusually weak tradewinds. The 1982-83 event is the most severe ever recorded. In the Galápagos, the sea-surface temperature reached 4.3°C above the mean in June 1983, the tradewinds failed almost completely, and on Santa Cruz where the mean annual rainfall (1965-81) is 374 mm, 3225 mm of rain fell between December 1982 and July 1983. The heaviest rain recorded was on Santa Fe on December 16th when 254 mm fell in 20 hours.

Increased sea temperatures and decreased salinity led to the disappearance of many marine organisms, including most of the algae, such as *Ulva*, *Centroceras*, and *Spermothamnium*, on which the marine iguanas normally feed. The intertidal and subtidal zones were colonized by several new species of algae. These include *Giffordia* and *Enteromorpha* spp. among others. This change in algal flora, coupled with extremely high sea levels and heavy swells which restricted access of marine iguanas to the feeding grounds was accompanied by massive mortality of

marine iguanas on all islands, although there are differences between islands in both overall and age-specific mortality rates.

Almost all adult marine iguanas had lost weight and in some populations on Fernandina there had been almost 50% mortality. Where there was little scope for intertidal feeding, but there were opportunities for subtidal feeding by diving, adult mortality was lighter and juvenile mortality extremely high. On Santa Fe where most of the feeding was intertidal, both juveniles and adults had suffered heavy mortality. The data from censuses of live animals on the one hand, and from collection of carcasses on the other, were subject to various and different biases, but overall there appears to have been about 45% mortality in the population of the study area over the 12 months from July 1982 to July 1983. The 1983 hatchlings appeared to have escaped abnormally high mortality, possibly because of their yolk-sac reserves and an ability to feed on different food items. Adult males suffered higher mortality than adult females - approximately 43% for all adult males and 32% for adult females.

There was a mean 30% weight loss among the surviving adults, and growth in terms of body length, had ceased altogether this year. Most juveniles had continued to increase in body length and weight, but at greatly decreased rates. Compared with their normal annual weight increase of 35%, the mean weight increase this year of 3-5 year olds was about 8%. Hatchlings normally more than double their weight during their first year (mean: 110% increase), but the mean weight increase of the 1982 hatchlings after one year was only 65%. Only the 1983 hatchlings were still relatively unaffected by the severe conditions two months after emergence.

Necropsies of dead animals revealed stomachs either completely empty or containing the largely

undigested remains of the filamentous alga, *Giffordia* with items of carrion such as pieces of dead crabs, sea lions and iguanas, and earth and stones and iguana skin (often taken from neighbor's flanks). *Giffordia* appeared difficult to digest, it hardly changed in appearance as it passed through the gut and the faeces which are normally liquid and amorphous, were dry and fibrous with food remains readily identifiable.

Fixed specimens of iguanas collected during the 1982-83 season were examined by Mr. J. Cooper at the Royal College of Surgeons to discover exact cause of death. Some animals had high loads of the trematode parasite *Iguanacola navicularis* in the gut, but this is unlikely to be the primary cause of death. Whole body X-rays and histological sections of the major organs show little sign of abnormality and the main problem appears to be impaction of the gut with hard, fibrous, algal material, presumably the result of the iguanas being unable to digest *Giffordia*. Most animals continued to feed on this alga although it often caused them to vomit, and they became gradually thinner and thinner until too weak to feed in the intertidal zone, at which point they fed on what carrion they could find, and finally died at between 50 and 60% of their body weight.

Digestibility of Algae

As it was impossible to use the digestive fluids of marine iguanas, experiments on digestibility of algae were performed with artificial saliva and sheep rumen fluid so that, at least, a comparison could be made between the different species of algae, some collected during, and others after El Niño. The main invading species of alga was *Giffordia mitchelliae*, which dominated the intertidal and splash zones. It has not been recorded before from the Galápagos but is probably normally present in low

frequency and increased in abundance enormously during El Niño because it possessed a much wider temperature tolerance than the normal food species of the red algal turf such as *Centroceras*, *Spermothamnium*, *Polysiphonia*, and *Gelidium* which were almost totally eliminated during El Niño.

The experiments showed that *Giffordia*, a brown alga, which was the main food species of the iguanas during the period of highest mortality, provided only 2.07 KJ/g of metabolizable energy, compared with up to 5.50 KJ/g for the red algae. It is likely that marine iguanas would obtain relatively even less energy from *Giffordia* as they are not ruminants, and the brown algae or Phaeophyta generally contain more cellulose (5-10% of dry matter) than the red algae.

The 1983-84 Field Season

Sea level and sea surface temperatures in Galápagos had returned to normal by September 1983 and the dense mat of *Giffordia* algae had begun to disappear by early November and was almost completely gone by December. The response of the marine iguanas was almost immediate. There was no more than normal mortality after August 1983 and the adults had returned to an average of ten percent below their pre-El Niño weights by November 1983. Overall mortality over the previous 12 months was estimated at 65% on Santa Fe, with the 1982 hatchlings suffering the highest mortality (90%). On other islands the overall mortality rate varied from 45% to 70% and was lowest of all at Caleta Webb, Isabela. It appears to have depended to some extent on the relative importance at each site of sub-tidal and inter-tidal feeding, with the subtidal feeders generally surviving better than intertidal feeders. Higher sea levels made intertidal feeding relatively more difficult than subtidal feeding, and the invading indigestible algae were more abundant in the inter-

by early to mid-March) there was less nesting than in a normal year but considerably more than on Santa Fe and Fernandina. However, it appeared that at Punta Nuñez and Caamaño many females were digging nests but not laying eggs. Hand examination of other digging females suggested that they were eggless. Subsequent excavation of some nest burrows failed to uncover any eggs and a large number were left unfinished. Some females undoubtedly did lay eggs and hatchlings have been reported from Academy Bay and North Seymour by various persons. Interestingly, no hatchlings have been reported from Fernandina or Santiago but some have been seen on Española.

CONCLUSIONS

The importance of El Niño in population regulation of marine iguanas has emerged. Extensive mortality reduced colonies to 30-55% of their former sizes. There is evidence that an El Niño event of magnitude comparable to the 1982-83 event has not occurred in the last 100 years. The normal reproductive rate of marine iguanas as recorded in the two years of study on Santa Fe before the 1982-83 El Niño is so low that an interval of at least 100 years, at that rate, would be needed for the population to recover to its pre-El Niño size. Recovery of decimated populations on some islands may be further slowed because of the presence of introduced predators (cats, rats, pigs, for example). For Santa Fe at least, these introduced animals are not present. On this island, the higher growth rate recorded in 1983 hatchlings indicate that growth survival and reproductive rates may become higher because of reduced competition for food and the population may recover relatively soon.

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EL NIÑO ON FERNANDINA

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Summary

The development of El Niño 1982-83 on the island of Fernandina is briefly described. Due to the warming of the sea, the local fur seal population severely suffered from food shortage; there was nearly complete mortality of young including 2 and 3 year olds. In the reproductive season of 1983, production of pups was still greatly reduced even though weather conditions were back to normal.

Additional observations on El Niño's effect on other species on Fernandina are also presented.

Resumen

El desarrollo de El Niño 1982-83 en la isla Fernandina se describe brevemente. Debido al calentamiento del mar, la población local de la foca peletera sufrió una severa disminución de alimento, lo cual causó una mortalidad casi total de jóvenes; incluyendo aquellos de dos y tres años de edad. Durante la estación reproductiva de 1983 los nacimientos continuaron reducidos (al 10% de los años anteriores), aunque las condiciones climáticas habían regresado a la normalidad.

Se presentan además otras observaciones sobre los efectos de El Niño en otras especies en Fernandina.

Fernandina, the most westerly island of the archipelago, is a huge active shield volcano whose barren flanks are pitted by many tiny volcanic cones. The cold Cromwell Current upwells along its western shore and has a great effect on the island's local climate. Virtually all the island's vegetation is found at higher elevations, about 500 m above sea level, where there is enough rainfall for growth. In the arid zone along the coast the only plants growing in any reasonable number are cacti (*Brachycereus* and *Jasminocereus*). The upwelling cold waters usually provide ample food for many of the marine animals of Galápagos inhabiting the rugged cliffs of the island, including the colorful 'sally light-foot' crab (*Grapsus grapsus*); the bizarre marine iguanas (*Amblyrhynchus cristatus*); well-known sea birds, such as the Galápagos penguin (*Spheniscus mendiculus*) and the flightless cormorant (*Nannopterum harrisii*); sea lions (*Zalophus californianus*) and fur seals (*Arctocephalus galapagoensis*). Galápagos marine mammals are exposed to an extreme range of environmental conditions; to cool water (15-17°C) while feeding in the sea and to a hot, arid environment while resting on lava shores.

In 1982, I came to Fernandina with my friend and assistant, Dr. Brigitte Ogrisegg, to study how the fur seals adjust their behavior to these extremes of environment. Cabo Hammond, a picturesque little bay on the south-west coast was chosen as the study site as it has an easily accessible fur seal colony. The animals here have been studied for several years by Dr. F. Trillmich and co-workers (Trillmich 1981, 1984; Trillmich and Mohren 1981; Trillmich, in press). Many of the fur seals have been tagged and their life

histories are partly known.

Although we had received information that El Niño conditions might form in the following months, Brigitte and I expected to find the climate hot and dry. The first months (August - October) were as expected, with drizzle (garúa) on just a few mornings. By mid December, however, we recorded rain on 36 out of 42 days - often continuous and heavy downpours which lasted for hours. With the onset of the rains, sea surface and air temperatures rose to 10°C above normal. Waterfalls rushed down the slopes of Fernandina. We could hear the roaring cascades from our camp at Cabo Hammond. With each passing day, the vegetation spread and grew thicker, flush with newly emerged, light green foliage. One of the palo santo trees (*Bursera graveolens*) near our camp - usually bone white and dry - suddenly sprouted fresh leaves. The normally barren, black lava coast became a spectacular display of flowering morning glory (*Ipomoea pes-caprea*), cyprus grass and tomatillo. Cacti burst into full bloom.

In late January the entire camp and surrounding area were flooded due to the spring tide with the high sea level (40 cm above normal; Wyrski 1984). February proved to be even worse - more rain in continuous downpours with thunder and lightning. Nevertheless, I continued to work until the end of March, when I finally decided to flee the El Niño altogether and to return only when the weather had improved.

When I came back to Cabo Hammond with Dr. F. Trillmich and T. Dellinger in late August 1983, the rains had stopped and the sea was back to its normal cool temperature (about 18°C) and remained so through our stay on Fernandina to early November (Fig. 3).

We were fortunate to have been able to observe and experience at close quarters the development of El Niño conditions and to see how the fur seals and



Figure 4. Juvenile Galápagos fur seal.

ashore again. Only at the age of about 2 years do the young start feeding by themselves, they may however, continue taking milk from their mother until even an older age.

By the reproductive season of 1982 the effect of El Niño on the fur seals could already be observed. Water temperature was then about 5°C above normal (Fig. 5).

The first abnormality we observed was the occurrence of stillbirths; newborn pups were also underweight. Mothers of pups remained at sea for unusually long periods, sometimes for a week or even longer, without coming back to nurse their young. Some of the pups lost weight rapidly. It appeared that the

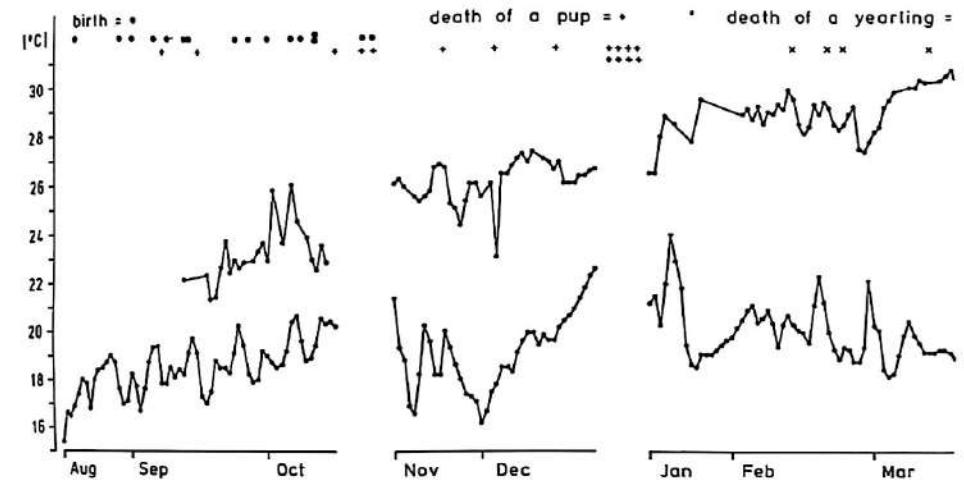


Figure 5. Upper curve: SST during 1982-83 at Cabo Hammond. Lower curve: SST from 1979-80 at nearby Northern Isabela. Dates of births and deaths of young fur seals in the study area are indicated at the top of the figure. (From Limberger et al. 1983).

females could not produce enough milk to keep their pups alive. Within 5 months of birth all but one pup (out of 90) in the entire colony had died. By February it was apparent that the older animals too, were suffering from food shortage. The 1-2 year olds were in very poor physical condition; some were even too weak to move around. The same was true for the adults. They appeared emaciated with their shoulder and girdle bones, normally surrounded by a thick layer of blubber, visible beneath their skins. The number of animals ashore, usually fairly constant throughout the year, ranging from 150-200 individuals in the colony studied, was greatly reduced. By February-March it was 70% less than in the preceding December. This not only reflects that animals were remaining at sea much longer than usual, but also an increased mortality rate. Additionally, it could



Figure 6. An 8-year old male fur seal during the period of food shortage.

be possible that animals went ashore at other places, as sea level at Cabo Hammond was high and the surf extremely strong. Other resting places might have been easier to reach and also less dangerous.

After our return in August 1983, we repeatedly checked for tagged animals on a 3 km stretch of shore line. Many adult animals were still missing; had they still been alive they should have been encoun-

tered at least once during the 11 weeks we spent at Cabo Hammond since fur seals normally return to the same locality. The number of animals in the colony was down by about 20%. Only one animal born in 1982 was found to have survived. Two and 3-year old animals were rarely encountered. Fully grown bulls were absent; they may not have been able to recover from their fast while defending their territories during the 1982 reproductive period. The number of pups born in 1983 was only about 10% of that in previous years, before the El Niño. Interestingly, the majority of them were females, whereas in other years the sex ratio of newborns was close to 1:1.

The El Niño produced both short and long term effects. During 1982-83, chronic food shortage caused massive mortality of young fur seals. The general physical condition and nutritional status of older and adult fur seals also deteriorated, which may have made them more susceptible to disease and predation. The majority of adult females probably aborted because developing embryos cause great nutritional stress. Thus, we found an extremely low birth rate in 1983.

Food shortage for the fur seals does not necessarily mean that its prey had disappeared altogether—it was merely out of reach for diving and foraging seals. According to investigations by Kooyman et al. (1983) fur seals forage mainly during the night. They feed on schools of fish and cephalopods which usually come up to the surface layer by vertical migration. In contrast to sea lions, which are diurnal and dive down to greater depths (200 m), fur seals stay in the upper 20 m. The huge schools of prey species, on which they feed, live only in cold water (Idyll 1973). However, by March 1983, the sea surface, normally below 20°C at that time of year, had reached 30°C. During El Niño the thermocline had dropped to a depth of about 200 m (see article by Kogelschatz et al., this volume). The fur seals'

prey therefore, remained inaccessible for diving fur seals. Due to that tremendous food shortage, the impact of El Niño was essentially zero reproduction in one year and a greatly reduced birth rate in the following year. Population mortality was high, essentially eliminating the three youngest age classes. Population numbers are about 80% of former levels.

The climate has apparently returned to normal by September 1983 and if it remains favourable for a sufficient length of time, those animals which were able to survive the last warm water event will build up and re-establish the Galápagos fur seal population.

El Niño Effects on other Species on Fernandina

During the warm water event of 1982-83 the sea lions at a colony south of Cabo Hammond, also apparently suffered from food shortage. This was not obvious in early 1983, when they appeared to be healthy, especially as many young were seen during various visits to the colony. However, by the end of 1983, they had changed the location of their colony to Cabo Hammond and only 3 yearlings and 10 2-year olds were seen out of a group of 220 animals. Such a shift of location may have been due to the high water levels during the period of El Niño. Their former colony site had been flooded repeatedly, as was indicated by deposits of sand and seaweed. Cabo Hammond was less prone to flooding than other areas. Pupping occurred much later in 1983 than in other years and only 6 sea lion pups could be found in the whole area, either due to low pregnancy rates or high death rate of pups. Visits to other sea lion colonies on other islands (Plazas, Santiago, Santa Fe, and Caamaño) confirmed this overall impression.

The marine iguanas suffered as well. During their egg laying season in January and February many of their eggs deposited in burrows on sandy beaches had been washed away by the high tides. Incidentally, the same happened to many turtle nests at Cabo Hammond. On our return in August 1983, we found many marine iguana skeletons randomly scattered around the beach. Many marine iguanas were weak and emaciated as they had not been able to reach their feeding grounds in the intertidal zone during the extended periods of heavy swell. We often observed Galápagos hawks (*Buteo galapagoensis*) attacking and eating the iguanas, which were easy prey as they had great difficulty finding suitable shelters inland where they had moved to escape exposure to the heavy breakers.

For several years now, a breeding pair of Galápagos hawks has been present near our camp. Like many other Galápagos birds, the hawk is very tame and easy to observe. The pair had one successful fledgling in 1981, which they chased off their territory when they started to breed towards the end of 1982. Their new chick hatched around Christmas but died in January - probably because of the heavy rain. In 1983 we did not see the pair attempt to breed, although they remained at Cabo Hammond.

A group of approximately 25 flightless cormorants at Cabo Hammond were not successful in rearing their young during 1982, although at least 2 nests contained offspring by September. By 1983, only 18 cormorants were left. Four pairs tried to breed again, but they had problems building a suitable nest as they could not find any of the brown algae (*Sargassum*) normally used as nesting material. As a substitute they used skeletons of marine iguanas starfish, grass and even a twig of *Sesuvium*, a plant of the salt marsh, which they collected from about 20 m inshore (Fig. 7).

Although the cormorants laid eggs and started

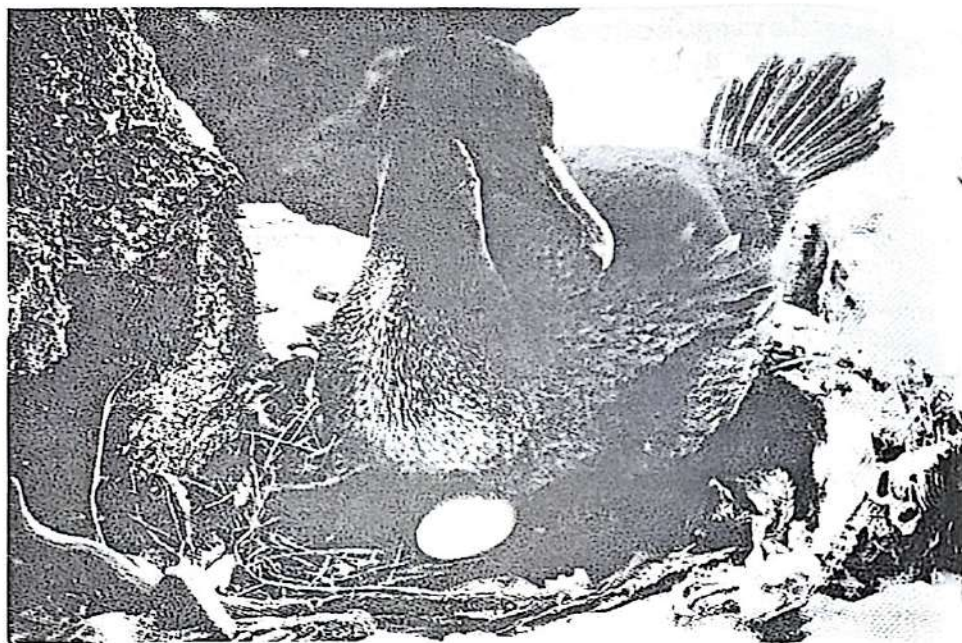


Figure 7. Flightless cormorant incubating upon a nest constructed of twigs, a marine iguana skeleton and starfish.

incubating, not a single chick hatched. Whether this was due to the unusual nesting material, or the poor nutritional condition of the female during the egg-laying period is not certain.

On the other hand, the local penguin population did not even attempt to breed in 1983. The size of the colony seemed to be the same as in previous years even though no immatures could be found in 1983. A maximum number of 13 penguins was counted during our stay in late 1983.

The swallow tailed gull (*Cregarus furcatus*) colony near Cabo Hammond did not seem to have decreased although colonies on other islands were re-

ported to have broken up.

Blue footed boobies (*Sula nebouxii*) never breed near Cabo Hammond. However, they can frequently be seen resting on the cliffs or feeding fish schools. Many boobies appeared to be ill and quite a few dead birds were encountered. These were events which we had never seen before and which only lasted for a short period during August 1983. Mass illness in sea birds is usually associated with bacterial infection or feeding in areas of red tides. Although such diseases are not recorded for the Galápagos, the boobies are known to have travelled long distances during El Niño. Some were even seen on the coast of Ecuador and the birds could have carried infectious diseases from there (observations by the Köllers of Santa Cruz).

The marine life around Fernandina was severely affected by El Niño. On our return in August 1983 almost all subtidal algae had disappeared, as well as many invertebrates. Surprisingly, there was an enormous increase in the growth of the green algae (*Ulva*) commonly known as sea lettuce. However, this algae had receded by November, when the calcareous algae reappeared as did the brown algae, which was quickly utilized by cormorants for their nests.

El Niño caused drastic mortality in several species. Even so, it should not be viewed as exclusively destructive. It is an unpredictable and recurrent event which is one of the selection pressures acting on the plants and animals of the Galápagos and a major factor in forming the unique composition of the islands' fauna and flora.

Acknowledgements

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THE WAVED ALBATROSS IN 1983 - EL NIÑO
LEADS TO COMPLETE BREEDING FAILURE

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Summary

Although about 15% of the Waved Albatross population on Española attempted to breed in 1983, not a single chick appears to have hatched. There is some evidence that the meagre breeding attempt was partly due to food shortage. For those females that did lay eggs, the heavy rains in May and June 1983 made incubation impossible.

The consequences of such a total breeding failure for the continuance of the population are discussed.

Resumen

Aunque alrededor de 15% de la población de albatros de la isla Española trataron de anidar en 1983, parece que ningún pollito eclosionó. Hay evidencia de que el pobre intento de anidación se debió en parte a la falta de alimentos. Para aquellas hembras que pusieron huevos, les fue imposible empollar debido a las torrenciales lluvias de Mayo y Junio de 1983.

Se discuten las consecuencias de tal fracaso reproductivo para la continuidad de la población de albatros.

Introduction

The 1983 Niño hit the Waved Albatross in two sensitive spots: its food supply and its breeding habitat.

The feeding range of the Waved Albatross extends from Galápagos to the coastal waters of Ecuador and Peru (Harris, 1973). The 1983 Niño affected this whole area, suppressing the cold and nutrient-laden Humboldt Current. It has been shown for previous Niños that the reduced plankton density cuts back the numbers of fish, and this in turn results in fewer 'guano birds' (Idyll, 1973; Wyrski, 1979). The albatross, which hunts for fish and squid in these waters, must also suffer a food shortage.

Except for a handful of stragglers, the Waved Albatross breeds exclusively on one small island of the Galápagos group: Española (Hood). Normally, Española is arid, its thorny bushes and low trees leaving many bare patches where the albatrosses breed. But in the first half of 1983 the Niño rains produced a thick carpet of vegetation. Parts of the island were swampy, and every few days large areas were flooded after heavy rains. The albatross breeding habitat was scarcely recognizable - an estimated 60% of the area used in previous years was inaccessible to the birds. A further setback in 1983 was the absence of strong, steady winds, which the albatrosses use for soaring flight and to break their speed when landing.

In the following report the albatrosses' breeding performance under these conditions is compared with results from 1981 and 1982, which are regarded as 'normal' years. (In 1982 the Niño did not set in until after the albatross incubation period, which seems to be by far the most critical time in determining breeding success.)

On Española the albatrosses inhabit a strip about 15 km long on the south and east coasts, where a high cliff offers an ideal take-off ramp. The species comprises some 12,000 breeding pairs (Harris, 1973). In non-Niño years most breeding adults reach Española in April, males arriving a few days before their females. Pairs are strictly monogamous. In April or May the female lays a single egg, very close to the site chosen in previous years. There is no nest. Incubation takes two months, with male and female alternating in four long stints. The chick is then fed by both parents for another 5 months. When chicks finally fledge, in November and December, most remaining albatrosses leave the island, avoiding the heat of January-March. Pairs breed annually. If the egg or chick is a loss, no new breeding attempt is made until the next year. The famous albatross courtship dances are performed not only by young, unmated birds, but also by mated pairs after a breeding attempt has failed.

Methods

1983 was the third season of my study on the breeding behaviour of the Waved Albatross. We worked at Punta Suárez, on the west tip of Española. Here, albatrosses have been banded with numbered monel rings more or less regularly since 1961, first by scientists of the Darwin Station (Levêque, 1963) and more recently by the National Park Service, so that about 60% of the Punta Suárez population is of known age.

My study area at Punta Suárez, roughly 3 ha in size, contained about 280 breeding pairs. Nearly all breeding birds and a number of non-breeders there were colour-banded in 1981, the combination of rings allowing individual identification at a distance. Records of the birds' activities and breeding success

were kept from May–October 1981, April–September 1982, and April–July 1983. In some aspects the data for 1981 are incomplete, as most birds were not colour-banded until after laying in that year.

Results

Several aspects of the albatrosses' breeding attempt in 1983 differed drastically from previous years.

At the start of the breeding season both males and females reached the island much later than in the two preceding 'normal' years. Fig. 1 compares the dates of arrival in the study area for 1982 and 1983. (The incomplete data for 1981 coincide well

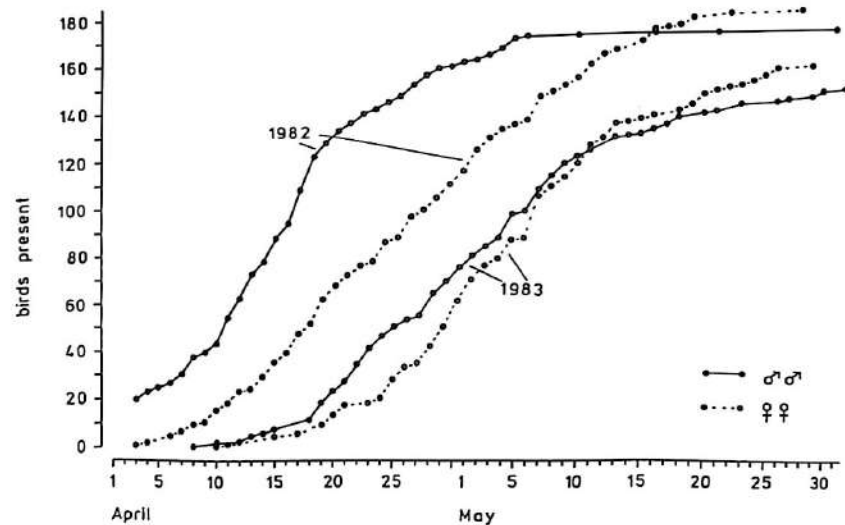


Figure 1. Dates of arrival of Waved Albatrosses on Española as cumulative distributions.

with the 1982 results.) In 1982 males began to arrive in the second half of March and females at the beginning of April. In the Niño year 1983 neither sex appeared before the second week of April. In 1982 the median arrival date for males was April 15th, for females April 25th. In 1983 it was May 3rd for males and May 5th for females. The delay in median arrival dates in 1983 was therefore 18 days for males and 10 days for females. Both sexes were greatly delayed in 1983, and males came only 2 days before females, instead of 10 days as in 1982.

Once they arrived on Española the albatrosses were faced with the exuberant Niño vegetation. Many customary landing sites were overgrown, and the remaining sites were used very cautiously, sometimes only after more than a hundred trial approaches. Landing is no easy operation for an albatross, and usually they take advantage of the strong winds to brake their speed; but there were no strong winds in 1983. Even when safely on the ground the birds' progress was laborious, as they often tangled their feet in creepers or were trapped in dense bushes. Because running was almost impossible they could not take off inland, and always had to make for the cliff edge to leave the island. Reduced mobility made the birds much more wary of humans.

In spite of these hindrances the birds seemed to make great efforts to reach their accustomed breeding sites. Individuals were frequently found trying to climb over dense shrubs and bushes 2 m high. Eventually most birds settled for some clearer spot as close as possible to their usual site, and aggregations formed in such relatively clear areas – unfortunately, precisely those areas most subject to flooding. During heavy rains, and directly after, the albatrosses usually stayed out at sea.

Under these adverse conditions it was surprising that the birds made even an attempt to breed; about 15% of the adult females in the study area did lay eggs. Fig. 2 shows the temporal distributions of egg-laying dates in 1982 and 1983. The late arrival on Española in 1983 delayed laying dates only slightly if at all, but the number of eggs laid was of course very small.

Why did some females lay eggs in 1983 and some not? No female laying in 1983 was less than 10 years old. In comparison, 33.7% of females laying in 1981 were younger than 10, and in 1982 this figure was 34.6%. The youngest birds laying both normal years were 5 years old. A Chi-square comparison of the age distributions of laying females in 1982 and 1983 indicates a difference significant at $p = 0.05$ ($df=3$). Age was therefore one important factor determining whether a female laid an egg in the Niño year. Another decisive factor was the female's previous breeding history.

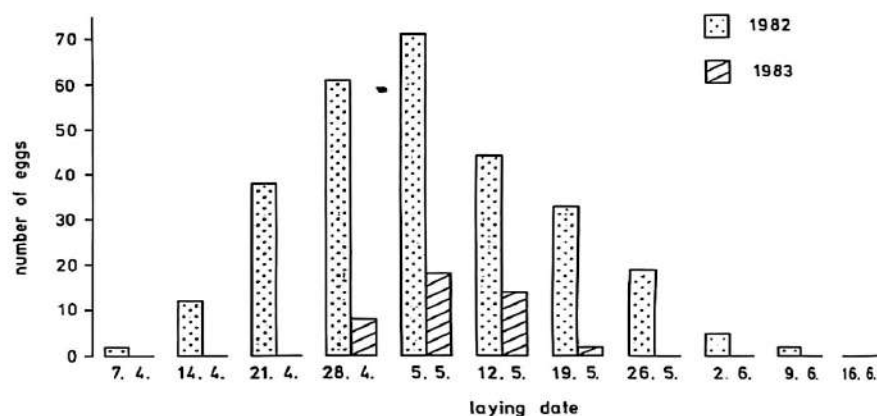


Figure 2. Histogram of egg laying dates, in classes of one week. Dates on the abscissa give the fourth day of every week.

In 1982, 133 females known to be 10 or more years old laid eggs in the study area; 14 of these raised chicks successfully. None of the successful females laid in 1983, but 20% of the unsuccessful ones did. This difference is significant at the $p = 0.05$ level (Chi-square test, $df=1$). The exertion of raising a chick in the previous year obviously reduced the likelihood of laying in 1983.

Not only did fewer females lay in 1983 - egg size itself was reduced. For 14 females egg size was measured both in 1982 and 1983. Of these, 12 had a smaller egg in the Niño year. The difference is significant at $p = 0.02$ (binomial test).

Only 42 females laid eggs in the study area in 1983. Incubating conditions were very harsh. After a few hours of torrential rain birds were sitting on a half-submerged egg, or even swimming on the surface of a pool trying to reach an egg at the bottom. Most eggs were abandoned quite soon. Fig. 3 gives the curves of egg survival (until broken or abandoned) for the 3 years of the study. Successful incubation requires about 63 days, but in 1983 no egg in the study area was incubated longer than 21

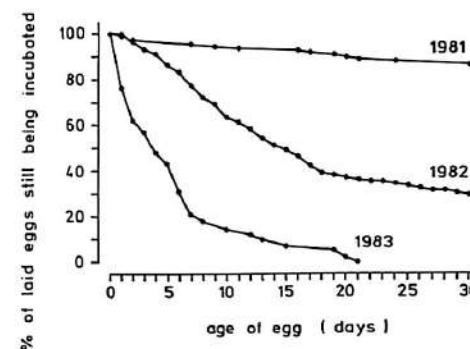


Figure 3. Egg survival until abandoned or broken.

days before being abandoned. Fig. 3 also shows the striking difference in the rates of egg abandonment between the years of 1981 and 1982. The immediate cause of egg abandonment in 1983 was all too obvious. Why so many eggs were abandoned in 1982 remains doubtful.

Egg abandonment in 1983 may not have been attributable to the females alone. Normally the first nest relief occurs between Day 1 and Day 16 after laying. For 23 of the eggs laid in the study area in 1983 both parents were known birds which had also bred there in 1982. In 1982 all males of these pairs returned to the site within 22 days of laying, and all that returned to find their female still incubating returned within 15 days. In 1983 only 7 out of these 23 males returned within 22 days of egg-laying, only 2 within 15 days; only one male managed to relieve its female. Even if the females had stayed on the eggs in spite of the adverse conditions, they would have had much longer to wait for relief.

All eggs in the study area had been given up by mid-June 1983. Not a single incubating albatross was found when checks were made in other parts of Punta Suárez and at Punta Cevallos on the island's eastern end. It seems probable that there was no breeding success at all for the whole population on Española in 1983. In July, weather conditions began to improve and the vegetation began to dry up and recede. Compared with other years courtship dances were unusually frequent, as all adult pairs had failed to breed and were therefore dancing.

Some birds did not reach Española that year. In contrast to the preceding years there was an especially high non-return rate of older birds. Birds that had been ringed as breeding adults (i.e., at least 5 years old) in 1961 or 1962 were at least

26 years old in 1983. 19.2% of such old birds recorded in 1982 had not returned to the study area by the end of July 1983, while of the younger birds only 3.5% were absent. This difference is significant at $p = 0.001$ (Chi-square test, $df=1$). Although birds that did not return to Española in 1983 were not necessarily dead, this result does suggest that older birds suffered the Niño effects more strongly than younger ones.

Discussion

The albatross breeding attempt in 1983 was a complete failure, due to various effects of the Niño phenomenon.

Several results show that the albatrosses suffered a food shortage before and into the breeding season of 1983. The birds were late in reaching Española, and many old and presumably weaker birds had not returned by the end of July. Many females that returned did not breed: Parents of 1982 chicks had probably been unable to recoup their energetic resources sufficiently to start afresh, and young females may have been in poor condition because they were as yet relatively inefficient foragers. But even females that did lay must have had reduced resources, as eggs were smaller than the year before. Males also had to contend with a shortage of food, as evidenced by their failure to return in time to relieve incubating females.

Not only conditions at sea, but those on Española itself may have prevented egg-laying. Females may be able to refrain from laying under conditions offering scant chance of egg survival. Also, many birds could not reach their accustomed breeding sites, which they normally use as a meeting place with the mate.

Finally, any eggs laid were doomed in advance; in May 1983 it was just not possible to keep an egg out of the water. Lack of food reduced the albatrosses' chance of breeding successfully, and dense vegetation shortened the odds still more. But the rain and floods were fatal.

Does every Niño year have such a devastating effect on the albatrosses? There have been four Niños, in 1965, 1969, 1972 and 1976 since records of the Española albatross population began in 1961. Of these, 1969 and 1976 were weak, and none was nearly as severe as 1983. In 1965 and 1969 hardly any chicks were reared, but the 1972 and 1976 Niños had no obvious detrimental effect on albatross breeding (Harris, 1969, 1973; National Park data). 1967 and 1968 were unsuccessful years although there was no Niño (Harris, 1973). There is clearly a connection between Niño conditions and albatross breeding failure, but it is not rigid. Different Niño manifestations vary in many parameters. Peterson (1967) attributed the 1965 failure to dense mosquitos driving the birds from their eggs - a factor that played no part in 1983. Harris (1969, 1973) suggests that the 1965 and 1969 failures may have been due to food shortage and heavy rains. This certainly holds true for 1983, but leaves unresolved why 1972 and 1976 had no effect.

Nevertheless, there are definitely some years when the species produces few or no offspring. Do such reverses threaten the survival of the Waved Albatross? Harris (1973) reports an annual adult mortality of 5%; National Park Service retrap data analysis and my own results confirm this. The population is constant if recruitment to the breeding pool balances loss. For an average recruitment age of 6 years, 17% breeding success would ensure a 5% recruitment. The estimated breeding success was 46% in 1981, 8% in 1982, and 0 in 1983. One good year

can easily make up for a total failure. The albatrosses of Española can take a Niño in their stride.

Acknowledgments

I would like to thank the personnel of the Galápagos National Park for their friendly cooperation and permission to use their records.

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FLUCTUACIONES EN LA POBLACION DE FRAGATAS
FREGATA MINOR EN LA BAHIA DARWIN, GENOVESA
DURANTE 1975-1983

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Resumen

La fluctuación en el tamaño de la población de fragatas (*Fregata minor*) en Bahía Darwin, Genovesa, durante 8 años es considerable (97-290 parejas; promedio 180). Sin embargo, en agosto 1983 sólo 11 parejas (6.1%) anidaban. Otras colonias fueron afectadas de maneras distintas: en isla Pitt anidaba el 65%, mientras en Española no se encontraron a parejas anidando.

Summary

Fluctuation in population size of the frigate bird colony (*Fregata minor*) in Darwin Bay, Genovesa, during 8 years of study was considerable (97-290 pairs; average 180). However, in August 1983 only 11 pairs (6.1%) were breeding. Other colonies were affected distinctly: on Pitt Islet, north of Isla San Cristóbal, 65% nested, whereas on Isla Española, no breeding pairs were encountered.

Desde 1975, cada año en julio/agosto se hicieron observaciones en una colonia de fragatas en Bahía Darwin en Genovesa, Galápagos. Los adultos fueron anillados para analizar el vínculo de la pareja y el

ciclo de reproducción (Hernández, en preparación). El área de estudio fue dividida en dos partes, una zona de turistas con las áreas visitadas y una zona no visitada de control. En ambas zonas todas las parejas que estaban anidando fueron registradas para evaluar el impacto turístico (Coello et al., 1977; de Vries, 1983). Además se ha estudiado la muda (De Korte y De Vries, 1978). En el año 1976 no se hicieron observaciones, mientras que en 1978 el estudio fue realizado por De Korte.

En el presente trabajo se informa sobre las fluctuaciones de la población de fragatas en 8 años, con referencia especial al año de El Niño 1982-83.

Resultados

Fluctuaciones en el número de parejas en Genovesa

Poco se conoce sobre la fluctuación en el número de parejas reproductoras. Si las fragatas tienen poca fidelidad al sitio de anidación, y aún más poca fidelidad a su colonia, observaciones a corto plazo tienen poca confiabilidad. Este trabajo presenta los resultados sobre el tamaño de una colonia por el lapso de ocho años. La colonia estudiada está bien marcada naturalmente, situada sobre un área con arbustos de *Cryptocarpus pyriformis* en la Bahía Darwin (ver Coello et al., 1977). La figura 1 muestra la fluctuación en el número de parejas y juveniles en el mes de agosto de cada año desde 1975.

El promedio del tamaño de la población reproductora es de 180 parejas con un máximo (290 parejas) en 1979 y un mínimo (97 parejas) en 1980. En agosto de 1983 encontramos sólo a 11 parejas que anidaban, lo que corresponde al 6.1% de la población promedio.

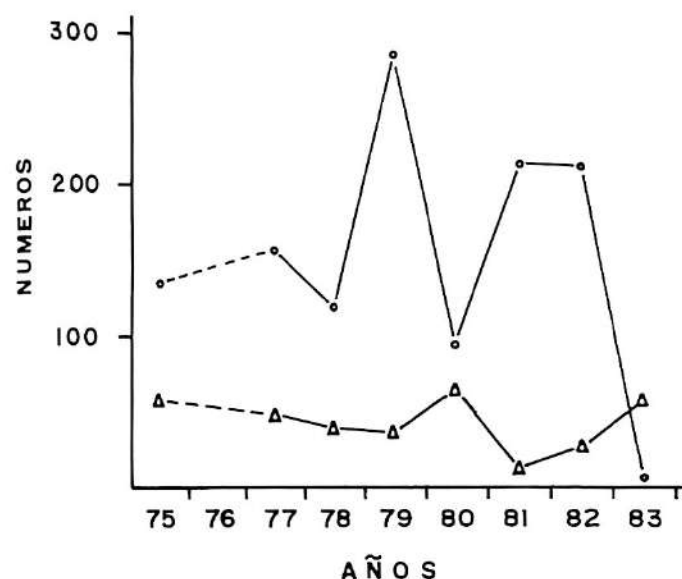


Figura 1. Fluctuación de la población de fragatas en la colonia en Bahía Darwin, en agosto de cada año. Círculos = parejas (huevo o pichón); triángulos = juveniles (pichones del año anterior).

El promedio del porcentaje de los juveniles sobrevivientes en agosto de cada año es del 21.1%, con el máximo en agosto de 1979 (27%) y el mínimo en agosto de 1982 (12.1%). Se nota que la sobrevivencia de los juveniles en el año de El Niño, en agosto 1983 ha sido alta (26.7%). Las condiciones oceanográficas aparentemente no afectaron de manera grave a las fuentes alimenticias de las fragatas.

En marzo/abril de 1983 había un gran número de machos en cortejo y parejas que incubaban (com. pers. de guías turísticos; lamentablemente nos faltan

censos detallados), lo cual indica que las condiciones eran favorables para comenzar la época de reproducción.

La Situación en Isla Pitt y Española

Por algunos años Gordillo ha hecho observaciones de las fragatas (*Fregata minor*) en Isla Pitt, un islote al norte de San Cristóbal. En agosto de 1975, 1976 y 1977 el número de parejas anidando fue 45, 42 y 34, respectivamente (promedio 40). En agosto de 1983, en compañía del Sr. Jacinto Gordillo y un estudiante de la Pontificia Universidad Católica del Ecuador (PUCE), el Sr. Carlos Valle, se hizo un censo completo de la colonia de las fragatas en Pitt. Se encontró un total de 26 parejas anidando y alrededor de 20 juveniles volando (sólo 6 fueron capturados y marcados).

La población reproductora en agosto de 1983 corresponde al 65% del promedio de las poblaciones de 1975-77.

La colonia de *Fregata minor* al norte de Punta Cevallos en Española ha sido observada esporádicamente, pero en visitas anteriores se contaron alrededor de 75-100 parejas. En agosto de 1983 no había parejas anidando, ni juveniles presentes en el área.

Las razones para las diferencias en el número de parejas que anidaban en Genovesa (6.1%), Pitt (65%), y Española (0%) no son claras. Puede ser que los 3 sitios hayan sido afectados en forma distinta por las lluvias fuertes (no hay datos de precipitación de la Isla Pitt y de Española).

Conclusiones

Durante 8 años de observación el número de parejas que anidaban en la colonia de Bahía Darwin fluctuó entre 97-290, con un promedio de 180. En agosto de 1983 sólo 11 parejas (6.1%) estuvieron con huevo o pichón pequeño. Este fracaso se debe a las lluvias fuertes y probablemente no a la escasez de alimento. Esta conclusión está basada en el número alto de juveniles presentes, los cuales aparentemente obtuvieron suficiente alimento para sobrevivir.

Se obtuvo un porcentaje distinto para el número de parejas que anidaban en Genovesa, Pitt, y Española lo cual indica que ciertas colonias fueron afectadas más por las condiciones meteorológicas y/o oceanográficas. No se conoce que las distintas colonias tengan diferentes regiones fijas en el océano donde, sin relación de una con otra, fluctúe la fuente alimenticia. Puede ser que Genovesa, Pitt, y Española fueron afectadas en forma distinta por las lluvias fuertes. Además, Genovesa estuvo plagada por mosquitos en los primeros meses del año 1983 (com. pers. P. Grant). En agosto de 1983 las 3 islas no tenían mayor número de mosquitos, por lo menos durante el día; en Genovesa al anochecer los mosquitos fueron una molestia para el hombre.

Agradecimientos

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ALTERACION EN LAS POBLACIONES DEL CORMORAN
NO VOLADOR, EL PINGÜINO Y OTRAS AVES MARINAS
EN GALAPAGOS POR EFECTO DE EL NIÑO 1982-83
Y SU SUBSECUENTE RECUPERACION

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Resumen

Los efectos de El Niño 1982-83 sobre las poblaciones de aves marinas de Galápagos se manifiestan en tres aspectos: el fracaso reproductivo casi total, la salida masiva de las aves de sus áreas de reproducción y la acentuada mortalidad. Las aves estudiadas corresponden a 11 especies de aves marinas residentes y los cambios en sus colonias se estudiaron en 12 sitios diferentes del archipiélago. A partir de julio de 1983, las aves regresaron y reiniciaron sus actividades de reproducción. Para enero de 1984 las colonias estaban nuevamente repletas de aves, en plena actividad reproductiva. Solamente para la fragata común (Fregata minor) hubo una demora en el reinicio de la reproducción. Esto se debe probablemente a la especialización alimentaria de esta especie.

Las poblaciones más severamente afectadas por El Niño 1982-83 fueron las del pingüino de Galápagos (Spheniscus mendiculus) y las del cormorán no volador (Nannopterum harrisi), que sufrieron una declinación poblacional del 78% y del 45% respectivamente. El cormorán no volador reinició su reproducción en julio de 1983 y para enero de 1984 el tamaño de su población ha aumentado considerablemente con los nuevos juveniles. La recuperación de los

pingüinos ha sido más lenta. En enero de 1984 iniciaron sus actividades reproductivas. El Niño 1982-83 afectó a las poblaciones de aves marinas de Galápagos, pero la recuperación de las mismas se ha reiniciado de inmediato.

Summary

The effects of the 1982-83 El Niño on populations of Galápagos marine birds was manifested in three ways: An almost complete reproductive failure, mass migration of birds from nesting areas and increased mortality. 11 species of resident marine birds were studied and changes in colonies were examined at 12 sites in the archipelago. Beginning in July 1983, birds returned to former colony areas and reinitiated reproductive activities. By January 1984, colonies were repopulated and there were clear signs of reproductive activity. Only the common frigate bird (*Fregata minor*) delayed recommencement of reproduction probably due to the specific food requirements of this species.

Populations most severely affected by the 1982-83 El Niño were the Galápagos penguin (*Spheniscus mendiculus*) and the flightless cormorant (*Nannopterum harrisi*) which suffered population declines of 78% and 45%, respectively. The flightless cormorant began reproducing in July 1983 and by January 1984, the population size had increased considerably with numerous young. Recuperation of penguins has been slower. In January 1984, penguins were beginning reproductive activities.

The 1982-83 El Niño affected several marine bird populations in Galápagos, but the recuperation of these populations began immediately following the cessation of adverse conditions.

INTRODUCCION

El Niño se caracteriza por la elevación de la temperatura superficial del agua del mar (Barber y Chavez, 1983), lo cual afecta de manera directa a la producción primaria. Esto a su vez conduce a un desequilibrio en los nichos tróficos superiores, peces, aves marinas y otros depredadores. Sin embargo, exceptuando ciertos fracasos en la reproducción de pingüinos (*Spheniscus mendiculus*), cormoranes (*Nannopterum harrisi*) y pelícanos (*Pelecanus occidentalis*), que podrían atribuirse al influjo de El Niño (Boersma, 1978), la literatura no ha reportado anteriormente cambios profundos en la biota galapagueña por efecto de este fenómeno.

En este trabajo se reporta el efecto negativo que tuvo El Niño 1982-83 sobre el tamaño de la población de cormoranes y pingüinos y sobre la mortalidad, movimientos de las colonias y reproducción de las aves marinas en el archipiélago. Se reporta además la situación inmediata post-El Niño. Las observaciones se iniciaron a finales de El Niño (julio de 1983) y se continuaron hasta enero de 1984.

METODOS

El presente trabajo está basado en las observaciones realizadas en los sitios del archipiélago que se señalan a continuación. Además se recibió información de guías auxiliares y naturalistas. Las observaciones se realizaron desde el barco o un bote pequeño a una distancia de 30 a 150 m de la orilla. Se utilizaron binoculares. Se determinó la presencia, número, estadio reproductivo y mortalidad de las aves. Además, en algunos sitios como se indica a continuación, se desembarcó para observar con detalle a las colonias.

Las islas visitadas fueron las siguientes:

Fernandina: Se realizaron dos recorridos minuciosos de aproximadamente 5 días cada uno alrededor de la costa de toda la isla. El primero se realizó entre el 29 de agosto y el 2 de septiembre de 1983 y el segundo en enero de 1984. En cada recorrido se contó el número de cormoranes y de pingüinos tanto en el agua como en la orilla. Se desembarcó en aquellos sitios en donde se encontraba una colonia de cormoranes para realizar un censo más detallado. Además, se hizo observaciones sobre las otras aves marinas.

Isabela: Se realizaron dos recorridos minuciosos de aproximadamente 5 días cada uno alrededor de la costa en dirección norte desde Punta García hasta Caleta Webb. Fechas: 3-7 de septiembre de 1983 y enero de 1984. La metodología de observación fue similar a la utilizada en la Isla Fernandina.

Tortuga: Se realizaron dos visitas, en septiembre de 1983 y en enero de 1984. En cada visita se desembarcó y se recorrió el interior del islote.

Santa Cruz: Se realizaron visitas mensuales de un día a las costas SE (desde Bahía Tortuga hasta Punta Núñez) y a la costa norte desde la playa Las Bachas hasta la zona del Canal de Itabaca). Estas visitas se realizaron entre julio de 1983 y enero de 1984. Las observaciones se hicieron durante caminatas por la orilla.

Plaza Sur: Se realizaron dos visitas de algunas horas de duración en octubre de 1983 y en enero de 1984. En cada oportunidad se desembarcó en la isla y se hizo una

inspección minuciosa del barranco sur.

San Cristóbal: En esta isla se visitaron por algunas horas la Playa Ochoa y el Islote Lobos. La Punta Pitt y el Islote Pitt fueron visitados por un total de tres días. Las visitas a cada sitio se realizaron en dos oportunidades: agosto y noviembre de 1983. En cada sitio se desembarcó y las observaciones se realizaron desde tierra.

Genovesa: Se realizaron dos visitas, en julio-agosto de 1983 y en noviembre de 1983. Cada visita duró aproximadamente dos semanas. Se hizo observaciones detenidas de las colonias de aves marinas en Bahía Darwin. Se realizaron también caminatas hacia el interior de la isla y por la costa, excepto la costa noreste.

Seymour Norte: Se visitó por un día en octubre de 1983. Se desembarcó y se recorrió toda el área de anidación de las aves marinas.

Daphne Mayor: fue visitada por algunas horas en octubre de 1983. En esa visita se desembarcó y se contaron las aves presentes.

Española: fue visitada por una vez en agosto de 1983. Se caminó por algunas horas en Punta Cevallos para observar a los albatros.

RESULTADOS Y DISCUSION

Las observaciones sobre la reproducción, movimientos y mortalidad de las aves marinas, realizadas en diferentes islas se han agrupado para dar una imagen global de su situación a finales de El Niño 1982-83 y en los meses siguientes. Se logró obtener

mayor información para 11 de las 19 especies de aves marinas residentes en el archipiélago. Estas especies y sus nombres comunes se dan en la Tabla 1.

La Reproducción de las Aves Marinas

La actividad reproductiva fue nula para siete de las 11 especies de aves marinas estudiadas (Tabla 1), las cuales interrumpieron su ciclo normal de reproducción durante los primeros ocho meses de 1983. En las especies restantes, el ciclo reproductivo no se interrumpió por completo, pero el éxito reproductivo fue bajo, observándose mortalidad en juveniles (nacidos en 1982) y pichones de las parejas que intentaron anidar durante los primeros meses de 1983.

El éxito reproductivo del albatros (*Diomedea irrorata*) también fue completamente nulo para 1983 y en agosto de 1983 ninguna de las parejas presentes en Española tenía huevo o pichón.

A partir de julio de 1983 algunas especies iniciaron un nuevo ciclo de reproducción, para noviembre de 1983 ya hubo abundante reproducción y para enero de 1984, la situación se ha normalizado por completo (Figura 1). La primera especie en iniciar la reproducción post-El Niño fue el cormorán no volador (desde principios de julio de 1983) y presumiblemente el pingüino de Galápagos, seguidos por una pequeña colonia de pelícanos en la costa oeste de Isabela (Puerto Fragata).

Movimientos de las Colonias de Aves Marinas

Los lugares donde se encontraban colonias de aves marinas quedaron desiertos durante los primeros ocho meses de 1983, notándose un abandono masivo, como no se había registrado anteriormente en todas las aves estudiadas (Tabla 1), excepto por la gaviota de lava que al parecer es bastante sedentaria.

Tabla 1. Estimación de los efectos de El Niño en las poblaciones de aves marinas. Las columnas de actividad reproductiva y movimientos poblacionales expresan el porcentaje estimado para cada especie. La tercera columna muestra el número aproximado de aves muertas encontradas durante los censos. D = desconocido.

Especie (nombre común)	Actividad Reproductiva	Movimientos Poblacionales	Individuos Encontrados Muertos
<u>Spheniscus mendiculus</u> (Pingüino)	0	10-30	>100
<u>Phaethon aethereus</u> (Pájaro tropical)	10	D	D
<u>Pelecanus occidentalis</u> (Pelecano)	0	90	>100
<u>Sula neboxii</u> (Piquero de patas azules)	0	90	>100
<u>Sula dactylatra</u> (Piquero enmascarado)	0	90	<50
<u>Sula sula</u> (Piquero de patas rojas)	0	90	<50
<u>Nannopterum harrisi</u> (Cormorán no volador)	0	0	>100
<u>Fregata minor</u> (Fragata común)	10	90	>100
<u>Fregata magnificens</u> (Fragata real)	40-60	40-60	<100
<u>Creagrus furcatus</u> (Gaviota de cola bifurcada)	0	90	<50
<u>Larus fuliginosus</u> (Gaviota de lava)	10	0	<50

Para el pájaro tropical no se tuvo información. Los primeros grupos de aves marinas que habían salido regresaron a sus sitios de reproducción a partir de julio de 1983. Para noviembre de 1983, las colonias que habían permanecido "vacías" por varios meses, se encontraban repletas.

Se desconocen los lugares a donde fueron las aves, pero es probable que se mantuvieran haciendo vida pelágica. Son pocos los registros y observaciones de pequeños grupos de aves marinas frente a las costas de Ecuador y Colombia y que probablemente provenían de las colonias galapagueñas.

Los pequeños grupos que no habían salido se desplazaban por diferentes sitios del archipiélago, como lo ocurrido con los piqueros de patas azules de Cabo Douglas (Fernandina) y de la colonia al sur de Caleta Tagus (Isabela). Estos dejaron sus colonias y al parecer se trasladaron por varios meses al área del Canal de Bolívar (cerca de Punta Espinosa en Fernandina). En este sitio a principios de septiembre de 1983 se contaron alrededor de 5000 individuos divididos en grupos de 200 a 1000 en plena actividad de pesca. Sin embargo en este mismo sitio, para enero de 1984 se encontró únicamente a un grupo de aproximadamente 300 piqueros. La gran mayoría había regresado; la colonia de Cabo Douglas y la de Isabela estaban totalmente repletas.

En Daphne Mayor, los piqueros, especialmente los de patas azules, salieron y en julio de 1983 habían muy pocos individuos (comm. pers. de guías turísticos). Para principios de octubre de 1983, se contó un total de 300 parejas, de las cuales el 15% (45 parejas) estaban anidando, la mayoría con un huevo. Casi todas las demás parejas presentaban una intensa actividad de cortejo. Similares actividades se observaron en el piquero enmascarado, aunque en menor grado.

Mortalidad

La mortalidad fue generalizada, principalmente en subadultos y juveniles, siendo particularmente notable en cuatro especies (piquero de patas azules, pelicano y ambas especies de fragatas) que se encontraban muertas por doquier (tabla 1). Valga como ejemplo los centenares de piqueros de patas azules muertos y desecados al sol sobre las piedras de lava o flotando en el agua alrededor de Fernandina. No obstante, las poblaciones más severamente afectadas fueron las de pingüinos y cormoranes. Sin embargo, para enero de 1984 se notó que la reproducción se había normalizado para la mayoría de las aves (Fig. 1).

Un caso atípico constituye *Fregata minor*. En esta especie, la mortalidad de juveniles continuó hasta noviembre de 1983. Para esta época, la situación del medio ambiente marino parecía totalmente reestablecida para las restantes aves; inclusive para el piquero de patas rojas, que según se conoce, al igual que *Fregata minor*, también se alimenta en aguas periféricas al archipiélago. Una posible explicación a este hecho sería, y como parece comprobarse, que las áreas marinas periféricas a Galápagos se reestablecieron más lentamente que las aguas interiores. Bajo estas circunstancias, una especie como el piquero de patas rojas, con mayor capacidad para conseguir alimento, peces voladores y otros capturados desde la superficie hasta cierta profundidad, no se hallaba ya en desventaja. En cambio, una especie con un nicho alimentario tan especializado como *Fregata minor*, que se alimenta a nivel superficial exclusivamente, se hallaría todavía en desventaja para conseguir alimento y más aún para satisfacer la demanda de alimento de su prole. Además, la reducción del número de aves marinas a quienes *Fregata minor* roba el alimento (cleptoparasitismo) también tuvo un efecto negativo, por lo que *Fregata minor* abandonó a su prole, la cual moría de inanición.

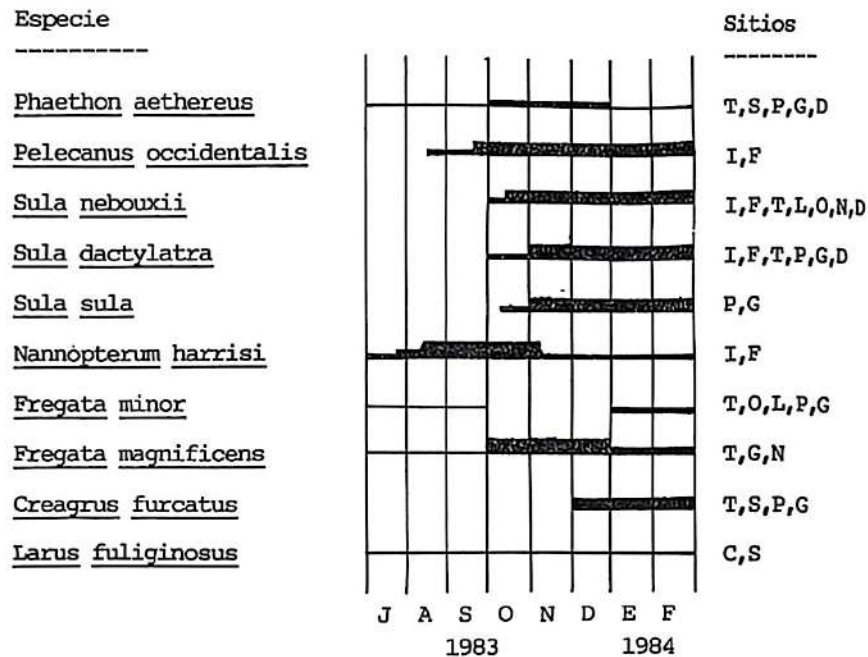


Figura 1. Reproducción en 10 especies de aves desde julio de 1983 hasta febrero de 1984. Las líneas mas delgadas indican reproducción esporádica, con una o pocas parejas en reproducción en por lo menos uno de los sitios indicados. El aumento en el grosor de las líneas indica mayor número de huevos y/o pichones en los diferentes sitios. Los sitios visitados corresponden a: I = Isabela; F = Fernandina; T = Isla Tortuga; C = Santa Cruz; S = Plaza Sur; L = Islote Lobos; O = Playa Ochoa; P = Islote y Punta Pitt; E = Espanola; G = Genovesa; N = Seymour Norte; D = Daphne Mayor.

La causa de la gran mortalidad se debió principalmente a la falta de alimento, pues los grandes bancos de peces disminuyeron durante El Niño. Esto encuentra su explicación en la reducción de la producción primaria. Desaparecieron *Ulva* y otros tipos de algas marinas que son habitualmente utilizadas por los cormoranes en la construcción de sus nidos. La reducción en la producción primaria sumada

a las alteraciones físico-químicas del medio ambiente marino condujeron a un desequilibrio de los niveles tróficos superiores y a una alteración del ciclo reproductivo de todas las aves marinas. Sin embargo, la recuperación se ha iniciado casi de inmediato.

Cambios en las Poblaciones de Cormoranes y Pingüinos

Las poblaciones de pingüinos (*Spheniscus mendiculus*) cormoranes (*Nannopterum harrisi*) tienen un tamaño bastante reducido y se han mantenido relativamente estables durante los últimos años (Fig. 2) (Boersma, 1977; Tindle, 1977; Harcourt, 1980). Durante El Niño 1982-83 sufrieron una declinación poblacional brusca del 45% para cormoranes y del 78% para pingüinos (comparado con el promedio de censos anteriores) y las poblaciones quedaron reducidas a un número extremadamente bajo (Valle 1983, 1984). La gran vulnerabilidad de estas especies adaptadas a las aguas más frías y presumiblemente las más ricas del archipiélago, ya fue sospechada por Boersma (1978) y se ha visto confirmada durante El Niño 1982-83, que provocó una alta mortalidad y un fracaso total en la reproducción (tabla 1).

La declinación poblacional de los cormoranes detectada en agosto-septiembre de 1983, con seguridad se debió a una elevada mortalidad antes que a movimientos afuera de su área normal de distribución. Esta especie tiene un marcado sedentarismo y nunca se ha observado individuos fuera de su área de distribución alrededor de Fernandina y la costa norte de Isabela, desde Caleta Webb hasta Punta García, ni siquiera en este año en que probablemente hubo marcada competencia por el alimento.

La situación de los pingüinos es bastante parecida. Sin embargo, los pingüinos normalmente salen de su área de reproducción, pues pequeños números se observan en diferentes sitios del archipiélago. Durante los meses más afectados por El Niño, el

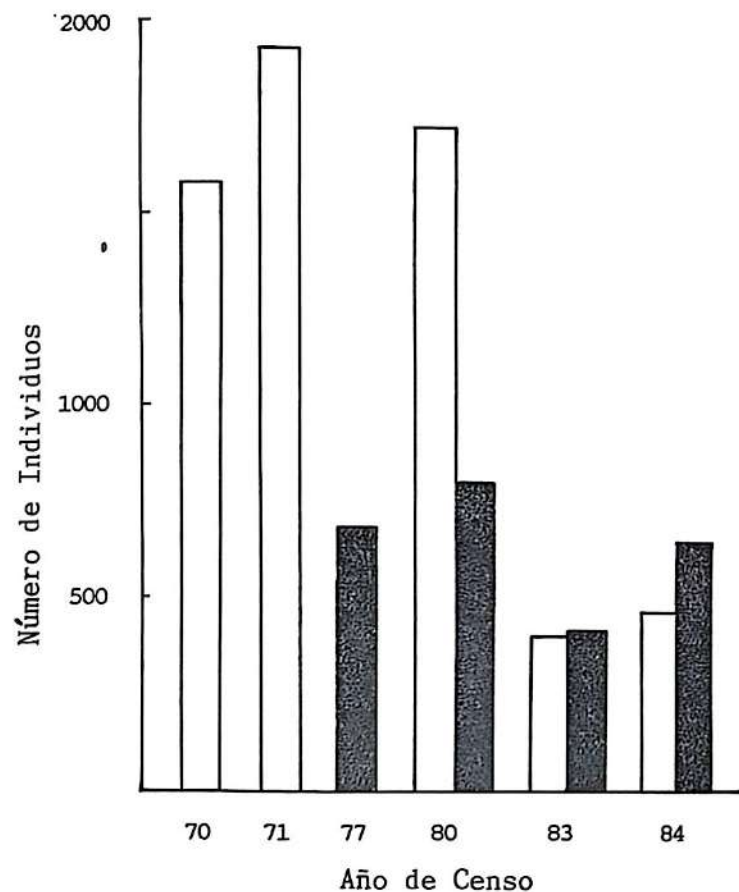


Figura 2. Número total de pingüinos (barras claras) y de cormoranes (barras oscuras) contados alrededor de Fernandina e Isabela en los diferentes censos. Censos de pingüinos: 1970 y 1971 (Boersma, 1977); 1980 (Harcourt, 1980); 1983 (29 agosto al 7 de septiembre) (Valle, 1983); 1984 (7-15 de enero de 1984) (Valle, 1984). Censos de cormoranes: 1977 (Tindle, 1977); 1980 (Harcourt, 1980); 1983 (29 de agosto al septiembre de 1983) (Valle, 1983); 1984 (7-15 de enero de 1984) (Valle, 1984).

número de individuos en otras áreas del archipiélago fue elevado.

Los cormoranes iniciaron su actividad reproductiva inmediatamente que cesaron los efectos de El Niño. En agosto-septiembre de 1983 se detectó una elevada actividad reproductiva. Había un gran número de parejas en cortejo o con huevo. Muy pocas tenían uno o dos pichones muy jóvenes y no se encontraron juveniles. Para enero de 1984 se observó menor actividad reproductiva que en agosto de 1983. Sin embargo, por la presencia de un gran número de juveniles y el incremento poblacional, se deduce que la reproducción post-El Niño tuvo un éxito elevado.

En contraste, para los pingüinos no se detectó reproducción en agosto-septiembre de 1983, pero para enero 1984 estaban en actividad de cortejo. La recuperación de su población ha ocurrido más lentamente que la de cormoranes (Figura 2).

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THE EFFECT OF EL NIÑO ON THE BREEDING OF THE
DARK-RUMPED PETREL ON CERRO PAJAS, FLOREANA

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Summary

Breeding success of the Dark-rumped Petrel on Floreana was greater in 1983 than in 1981 (46% versus 30%). Nest desertion and natural burrow and habitat destruction rose from a combined 20.7% of the losses in 1981 to 67.8% in 1983. The greater success in 1983 was attributable to the rat control program (in 1981 there was 24.1% of egg losses through predation, versus 0% in 1983). There was a significant change in body growth rate of chicks between the two years, but no differences were found between the weights at which the young fledged. Birds fledged earlier in 1981 than in 1983 (107 versus 118 days).

Resumen

El éxito reproductivo del Petrel Hawaiano en Floreana fue mayor en 1983 que en 1981 (46% versus 30%). El abandono del nido y la destrucción natural del hábitat y de los nidos aumentaron desde un 20.7% de pérdidas en 1981 a un 67.8% en 1983. El mayor éxito reproductivo de 1983 se debió a los programas de control de ratas (en 1981 hubo 24.1% de pérdida de huevos por predación, versus 0% en 1983). Hubo un cambio significativo en la velocidad del crecimiento del cuerpo de los polluelos en estos dos años, pero no se encontraron diferencias en el peso con el cual los jóvenes abandonaron el nido. Los jóvenes abandonaron el nido más pronto en 1981 que en 1983 (107 versus 118 días).

The Dark-rumped Petrel (*Pterodroma phaeopygia*) is a little known, gull-sized, sea bird which nests only in the Galápagos and Hawaiian archipelagos. In both places the bird is in danger of extinction; populations number in the hundreds in Hawaii while as many as 10,000 pairs may still survive in the Galápagos. In Galápagos major nesting colonies have been located on the islands of Santa Cruz, San Cristóbal, Santiago and Floreana, and there is a possibility that the birds also nest on Isabela. The petrel is a pelagic feeder and can easily fly long distances to obtain the small cephalopods and fish which are its main diet. Breeding adults normally spend approximately 9 months at the nesting sites and appear to be faithful, not only to their particular colony, but also to their individual nests. The timing of the breeding season varies from island to island and also apparently from colony to colony within the same island. Consequently, there are breeding petrels present in Galápagos during the entire year, albeit on different islands and in different stages of nesting.

Petrels nest in a variety of terrains all located in the highland sections of the islands. Nest sites vary from soft soil underground burrows excavated by the birds to rocky caves and crevices. It is thought that originally these birds nested in great numbers and in widespread areas of the highlands. With the introduction of grazing and foraging animals and the use of many of these areas for cultivation, petrel populations have declined and their colonies have become restricted to the more vertical flanks of extinct volcanoes (called cerros), the protected walls of water gullies, and the less accessible caves of rocky areas.

Normally, the petrels return to the islands for about one month of aerial courtship before their single egg is laid. Both parents share the incubation and when the chick is hatched, approximately

50 days later, both adults bring food to the young. The chick remains in the nest for 3 to 4 months before fledging and then adults and young abandon the island until the next breeding season begins.

Floreana

With the support of the World Wildlife Fund, we have been working with the petrel population on Isla Floreana for the past 3 years. There are several colonies on the island, but 85% of the estimated 1500 pairs nest in the crater of the extinct volcano known as Cerro Pajas. The birds return here in December-January, lay eggs from January through March, and the young fledge from July through September.

In the first year of the study, directed by Dr. Malcolm Coulter, we estimated that the petrel population was declining by about 33% per year and could become extinct on Floreana in 10-15 years. Predation by feral animals (rats, cats, and pigs) and habitat destruction by both domestic and feral animals (goats, burros, and cattle) at the nesting site appear to be the most serious threats that the species faces. Consequently, a program was developed with advice from the World Wildlife Fund, the International Council for Bird Protection, New Zealand Wildlife Service, and the U.S. Fish and Wildlife Service, and implemented in the autumn of 1982 to help control predation, in particular, that of the black rat (*Rattus rattus*) on eggs and young chicks.

The migration of most feral animals into the colony area is controlled through combined hunting and trapping pressure. In the month of December, before petrels return to court, the resident rodent population within the colony area is reduced by poisoning with Racumin (R) (an anti-coagulant) and

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the poison is maintained through June, when petrel chicks are old enough to defend themselves from rodent attacks. The suggested method to eliminate domestic cattle and burros from the colony is to fence the cerro and thus bar their entrance, but so far sufficient funds have not been available to implement this phase of the program.

We have just completed the first year of feral animal control at the Cerro Pajas colony and can report a 16% rise in number of fledglings from our monitored segment of the population. This is a distinct reversal of the previous downward trend and is a hopeful sign. However, most of the 1983 breeding season, January through September, coincided with abundant rainfall experienced with the appearance of the El Niño phenomenon in November, 1982. The changes in terrestrial habitats as well as those produced in the marine environment (warmer water temperatures and lower ocean productivity) combined for some unusual effects upon our study this year. It is impossible to claim a great success for the control program without first considering what effect El Niño may have had on the Dark-rumped Petrel.

El Niño

According to the precipitation data collected at our main weather station located in the central highlands of Floreana, rainfall began to increase in November 1982, and remained high through mid-July, 1983 (Figure 1). During that time, 190.5 inches of rain fell. In the entire previous year (October 1981 to October 1982), 29.4 inches were recorded and in the 3 months since (August 1983 to October 1983), 4.1 inches have fallen. The changes in vegetation caused by the increased precipitation were tremendous. In the crater of Cerro Pajas, *Scaevola pedunculata* and *Lantana camara* proliferated while *L. camara* became dominant on the exterior flanks. In

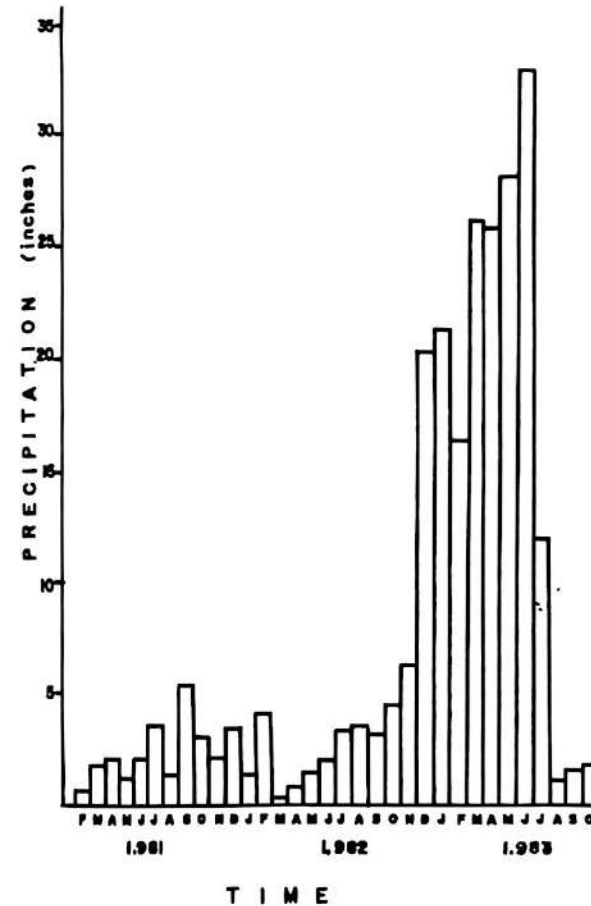


Figure 1. Total monthly precipitation, Isla Floreana. Weather station located at approximately 300 meters altitude.

general, ground vegetation became exceedingly dense, choking off most trails in the area. The entire fruit crop of *Psidium guajava* was suppressed, while that of *L. camara* and *Croton scouleri* was more abundant. The frequency of rock falls and land slides increased as the ground became super-saturated with water, making working conditions more hazardous.

Changes in the marine environment were equally drastic and are treated in detail elsewhere in this volume. However, it is interesting to note that marine productivity was sharply curtailed during this period due to the high temperature of the waters surrounding Galápagos, thus sharply reducing the amount of food available to sea birds.

The Black Rat

In a previous study in Galápagos (Clark 1980) it was found that feral rodent populations breed normally only once or twice a year, principally at the onset of the normal 'rainy' season in December-January and perhaps during the moist garúa season as well. However, the necropsies we performed on trapped rats, coupled with those of B. Barnett (unpublished) from November 1982 through October 1983 consistently showed a high percentage of reproducing females throughout the eleven month period. No seasonal variation was observed. Availability of adequate food, water and habitat may no longer have been the limiting factors on rodent reproduction during El Niño and an increase in the rat population seems probable.

In a 'normal' year consumption of poisoned rat bait used in the control program is expected to be initially high, until the resident rodent population is decreased in the target area, and then to remain at a low level as rodents which migrate from surrounding areas are also eliminated. During the program, in fact, bait consumption was highest in

April and May, at the end of the campaign, indicating that our study area experienced repeated and large migrations from unaffected rat populations outside of the Cerro. Again, it seems probable that a large rat population, continually reproducing, increased migration levels over a much longer season than has been observed under drier conditions.

Monitoring the Dark-rumped Petrel

This year we continued monitoring the nesting attempts of adult petrels and growth of petrel chicks as in previous years, but increased our sample size from 64 to 104 active nests. Adult birds are weighed banded and morphological measurements are taken. The progress of all the sample nests is checked weekly, while a smaller number are selected and checked more frequently (this minimizes destroying the fragile habitat). Weight and growth measurements are made once a week for all chicks. We would like to present some comparisons between the findings of the El Niño year and those of the drier year 1981.

From Figure 2, we had 48 birds fledge from 104 nests (46%) in 1983 compared with 13 fledged from 43 active nests in 1981 (30%), an increase of 16%. Causes of egg and chick losses are listed in Table 1. The initiation of the rodent control program coincided with a drop in predation losses from 1981's 9 cases (31%) to near zero in 1983. In light of the extreme difference in climatic conditions it is difficult to claim that the control campaign was entirely responsible for this dramatic drop, however, considering the probable increase in rat population, it certainly helped to reduce these losses.

On the other hand, nest desertion and natural burrow and habitat destruction rose from a combined 20.7% of the losses in 1981 to 67.8% in 1983. We

T A B L E 1
Losses of Petrel Eggs and Chicks

Cause	1981		1983	
	Number of losses	Percentage of losses	Number of losses	Percentage of losses
Nest destroyed	1	3.5	8	14.3
Egg predated	7	24.1	0	—
Egg abandoned/rotten	5	17.2	25	44.6
Egg undetermined	6	20.7	7	12.5
Chick predated	2	6.9	0	—
Chick abandoned	0	—	5	8.9
Chick malnourished	0	—	6	10.7
Chick deformed	0	—	1	1.8
Chick undetermined	8	27.6	4	7.1
T o t a l s	29	100	56	100

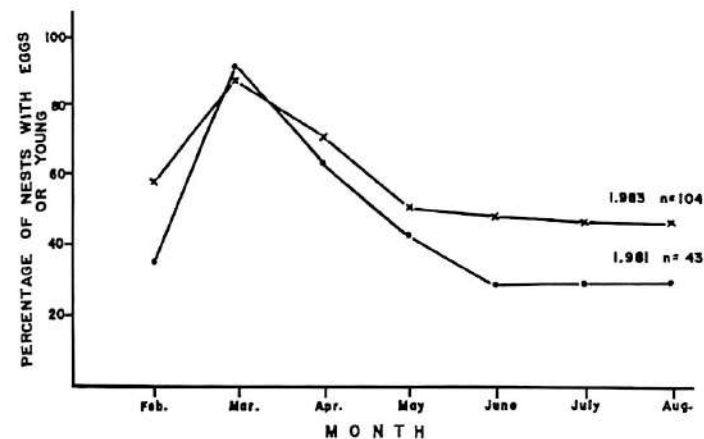


Figure 2. Comparison of Hawaiian petrel nesting success between 1981 and 1983.

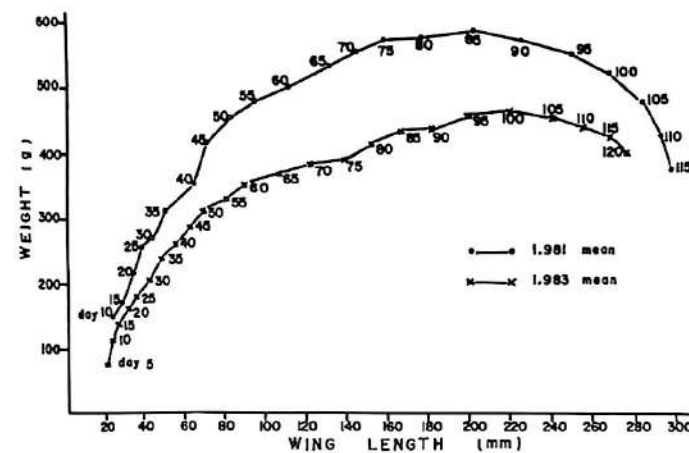


Figure 3. Comparison of Hawaiian petrel chick growth between 1981 and 1983.

feel a major cause of this rise was the extremely wet conditions encountered in 1983, which led to a sharp rise in nest inundations by rain water run-off and burrow collapses. Again, in 1983, we observed 5 cases where young chicks were abandoned and 6 where older chicks clearly died of malnutrition. These cases do not exist from the drier years 1981 and 1982. It is a well-known sea bird reproductive strategy to attempt breeding only when food resources are abundant and to abandon the attempt if food later becomes limited. We suggest that the sharply reduced food supplies engendered by the El Niño's effect on marine food production is the cause of many of the nest desertion, chick abandonment and malnutrition cases observed this year.

A significant change in body growth rate of chicks between the years under consideration is noted when weights and wing lengths are compared. Table 2 includes these figures and clearly shows that by 45 days mean weight, 289.5 ± 68.92 g. ($t = 5.81$, ≤ 0.001) and mean wing length, 65.25 ± 9.39 mm ($t = 2.14$, ≤ 0.05) for 1983 are well below the mean weight, 407.2 ± 47.1 g. and wing length, 71.0 ± 4.45 mm for 1981 (t statistics from Ostle, 1963). However, after the 105th day there are no differences in mean weights and wing lengths of birds fledged in both years.

Normally, a chick's weight increases over the first 3 months and then decreases somewhat as it nears fledging. Figure 3 illustrates the mean growth curves achieved for both years and it is possible to see that the peak weights for fledglings in 1981 were greater than those in 1983 (1981 peaked at 634.9 ± 58.84 g. and differs, $t = -7.04$, ≤ 0.001 from the 1983 peak of 542.3 ± 68.98 g.). These peak weights also occurred earlier in 1981 (at 82.6 ± 11.3 days) and differ ($t = -2.77$, ≤ 0.01) from the peak age in 1983 (96.7 ± 17.25 days).

Although no differences were found between the weights at which the young fledged in both years, Figure 4 clearly shows that 1981 chicks fledged at a younger age ($t = -6.05$, ≤ 0.001) than those

TABLE 2
Comparison of Chick Weight and Wing Length 1981 and 1983

Day	n	1 9 8 1 (1)		n	1 9 8 3 (1)		T	p
		$\bar{x}$	s.d.		$\bar{x}$	s.d.		
A. Weight (g)								
15	12	155.7	43.43	50	141.2	44.34	1.02	< 0.4
30	13	284.8	42.42	53	203.4	54.85	4.99	< 0.001
45	13	407.2	47.10	52	289.5	68.92	5.81	< 0.001
60	13	496.9	65.29	52	357.8	79.94	6.17	< 0.001
90	13	593.0	68.98	49	437.7	78.64	5.67	< 0.001
105	10	478.2	50.23	49	453.3	86.33	0.88	< 0.4
B. Wing Length (mm)								
15	12	28.6	2.88	50	29.5	3.57	-0.79	< 0.5
30	13	45.6	3.69	53	43.7	7.13	0.94	< 0.4
45	13	71.0	4.45	52	65.3	9.39	2.14	< 0.05
60	13	114.3	10.47	52	95.3	16.12	4.05	< 0.001
90	13	225.8	15.01	49	184.8	21.12	6.55	< 0.001
105	9	282.6	12.95	49	239.1	27.37	4.62	< 0.001

(1) n, number; $\bar{x}$, mean; s.d., standard deviation; T, t statistics; P, probability

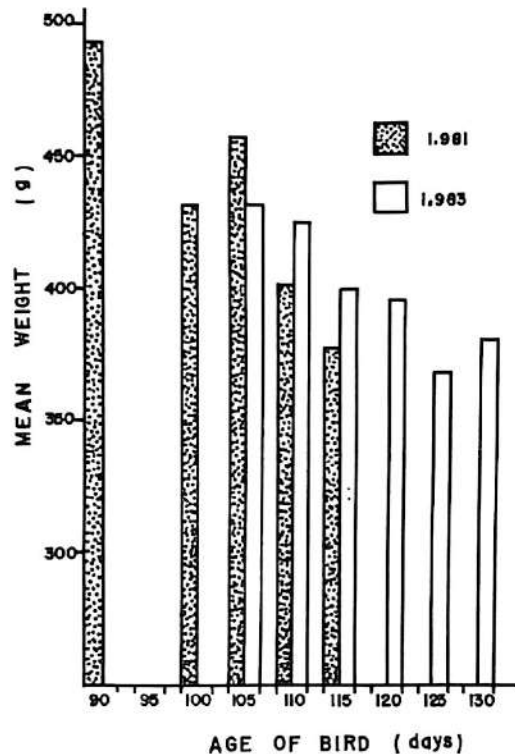


Figure 4. Comparison of fledging weight versus age of bird for 1981 and 1983.

in 1983 (107 ± 6.41 days in 1981 and 118.5 ± 5.67 days in 1983). We feel sure that the probable cause of this slower chick growth, lower peak weight, and retarded fledging age is the abnormally low food supply produced by El Niño in 1983.

Despite the combined effects of limited food supply and higher rat population, the success of petrel nesting rose 16% over 1981, reversing the 33% decrease observed in previous years. We feel that the decreased rodent population in the colony contributed greatly to the overall success in this 1983 year. However, due to the extreme difference in precipitation between the control and non-control years it is impossible to determine the real effect of the control program without more time to substantiate it. We hope to continue with the entire feral animal control effort long enough to ensure that the Dark-rumped Petrel population recuperates to a point where it can sustain itself and is no longer in danger of extinction from impacts of introduced species on the petrel's nesting colonies.

Acknowledgements

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CAMBIOS EN LA LAGUNA DEL CEMENTERIO Y EN PUERTO VILLAMIL, ISLA ISABELA, CAUSADOS POR EL FENOMENO "EL NIÑO" EN 1982-1983

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Resumen

La duna de la laguna del Cementerio se rompió a consecuencia de un fuerte aguaje en enero de 1983. El agua de mar entró en la laguna, elevó su nivel y cambió sus características. Como resultado, los sitios de anidación de los flamencos (*Phoenicopiterus ruber*) quedaron totalmente sumergidos y no hubo reproducción de estas aves en 1982-1983. Además, el recurso ictiológico que albergaba esta laguna, "lisas" (*Mugil sp.*) y "diablos" (*Chanos chanos*) desapareció por espacio de diez meses. Posteriormente, algunos pescadores reanudaron sus actividades y lograron capturar peces de los dos tipos, pero de tamaño mediano.

En Puerto Villamil, muchas casas se inundaron a causa de las fuertes precipitaciones. Algunas familias se vieron obligadas a abandonar sus viviendas y a pedir alojamiento sea en casas particulares o institucionales, a donde el nivel del agua no había subido.

Summary

*In January 1983, unusually high tides destroyed the dune at the "poza del Cementerio". Sea water entered the lagoon, raising the water level and altering its characteristics. As a result, the nesting sites of flamingos (*Phoenicopterus ruber*) were totally submerged. These birds did not reproduce at this site during 1982-1983. In addition, the lagoon fish resources, "lisas" (*Mugil* sp.) and "diablos" (*Chanos chanos*), disappeared for a period of ten months. Later, some fishermen began to fish again and were able to capture medium-sized fish of these two species.*

In Puerto Villamil, many houses were flooded due to the heavy rains. Some families had to leave their homes and to seek lodging in private homes or in the buildings of some institutions.

Cambios en la laguna del Cementerio

El día 1 de enero de 1983 hubo un fuerte aguaje. El agua del mar subió considerablemente en la playa del "Cementerio". Por la fuerza poderosa de las olas, se rompió la duna en dos sitios. El primero se encuentra pasando el faro (dirección oeste de la población de Puerto Villamil). El segundo sitio de ruptura se encontraba pasando el Cementerio, en donde termina la playa.

Al siguiente día debido a la gran cantidad de fango que salió de la laguna, el agua de mar se contaminó desde la zona del Cementerio hasta la rada del Puerto, tomando un color turbio. Además despedía un olor repugnante, característico del fango que se encontraba dentro de la poza.

La extensión aproximada de las zanjias que se

formaron era de 40 m de largo por 15 m de ancho. La profundidad variaba desde 0.8 m hasta 1.3 m. En los sitios mencionados se producían fuertes corrientes que se asemejaban a las de un río caudaloso, y tenían variación de acuerdo a la marea. Cuando comenzaba a subir la marea, la corriente se producía de Sur a Norte; y cuando la marea comenzaba a bajar, la corriente era en sentido contrario.

Para esta laguna mantengo un registro de nivel del agua. Cuando se produjo este fenómeno, noté que el nivel máximo del agua dentro de la laguna subió a 1.35 m, el nivel más bajo era de 0.28 m. La temperatura del agua en la poza era de 30°C a las 11.00 horas del día 3 de enero de 1983. El nivel normal del agua en la laguna es de 0.56 m y 0.40 m, máximo y mínimo en su orden. Noté la diferencia.

Intervención del hombre

Las autoridades locales, preocupadas por el cambio de la laguna, decidieron cerrar los dos canales. El trabajo se realizó con el personal y equipo caminero del Ilustre Municipio y del Instituto Nacional Galápagos. El cerramiento de los canales se realizó mediante la colocación de material de relleno, en especial de rocas muy grandes, hasta levantar muros que parecían lo suficientemente fuertes para contener la entrada o salida del agua. Esta obra dió los resultados esperados y se logró impedir el flujo del agua.

Al cabo de dos meses desde el término de la construcción de los muros, el mar embancó una enorme cantidad de arena a lo largo de toda la playa. Los muros de roca desaparecieron casi por completo, quedando visible muy poca cantidad de este material. Sin embargo, la laguna todavía mantiene elevado el nivel del agua.

Evacuación de aves

Como es conocido, los flamencos (*Phoenicopterus ruber*) anidan dentro de esta laguna. Debido a la subida del nivel del agua, los sitios de anidación quedaron totalmente sumergidos. Los flamencos abandonaron estos sitios de anidación. Cabe mencionar que esta laguna era un excelente lugar de anidación, habiéndose localizado cinco sitios diferentes en donde estas aves construían sus nidos.

Un año después del aguaje (enero de 1984), no se observan flamencos como en épocas anteriores; han abandonado esta laguna, y seguramente por la subida del nivel del agua tienen grandes dificultades para buscar su alimento. Hay algunos grupos de flamencos que permanecen en nuevos sitios, como son la poza del "Manzanillo", la poza del "Junco" y la poza de la "Puerta de Jelf". La poza del "Junco" se ha transformado en excelente sitio de reproducción de tres especies de aves que antes anidaban en la poza del cementerio. Estas son: Tero real (*Himantopus himantopus*), gallaretas (*Neocrex erythrops*) y patillos (*Anas bahamensis*). Las dos últimas especies anidan en mayor cantidad y tienen su habitat en este nuevo lugar.

Recurso ictiológico

Los pescadores locales habían explotado por algunas décadas a los peces que albergaba la poza del Cementerio. Los peces corresponden a los comunmente llamados "lisas" (*Mugil sp.*) y "diablos" (*Chanos chanos*). Estos peces desaparecieron temporalmente de la laguna a consecuencia de la gran cantidad de agua de mar que entraba y salía por las aberturas en la duna. Es factible que algunos peces hayan permanecido en la laguna, pues la poza mantenía porciones de agua en sus extremos Este y Oeste. La parte cen-

tral de la laguna quedaba sin agua cuando bajaba la marea, entonces era posible observar el fango y la gran cantidad de arena que entró desde el mar hacia la laguna.

El día 8 de marzo de 1983 observé por algunas horas el agua que salía por una de las aberturas de la duna desde la poza hacia el mar. No encontré que los peces abandonen la laguna. Por el contrario, las lisas muy pequeñas y de tamaño mediano entraban a la laguna con la corriente en contra. Cuando encontraban algún obstáculo, inclusive saltaban y entraban a la poza. Comprobé que en tres horas entraron 12 grupos de lisas. La cantidad variaba entre 20 a 50 individuos aproximadamente. En ningún momento los peces salían de la laguna al mar.

Después de diez meses (enero 1984), algunas personas reanudaron sus faenas de pesca y han logrado capturar con sus redes a peces de los dos tipos antes citados, pero de tamaño mediano. Además han cogido parvos (*Lutjanus sp.*) y róbalo (*Centropomus sp.*), pero estos últimos en muy poca cantidad. Parece por tanto, que el recurso ictiológico se ha renovado en un período relativamente corto.

La vegetación

La vegetación de jelf (*Conocarpus erecta*) que se encuentra alrededor y en el centro de la laguna del Cementerio comenzó a morir después de dos meses del aguaje que rompió la duna. Posiblemente esto se deba al cambio de salinidad producido por el ingreso de agua de mar a la poza. El mangle rojo (*Rhizophora mangle*) no fue afectado; esta especie parece ser más resistente. En enero de 1984 se notó que la laguna comenzó a repoblarse de jelf (*C. erecta*). Además junto a las aberturas de la duna se pudo encontrar a muchas plantas jóvenes de mangle rojo. La altura de estas plantas va desde 0.2 a 0.8 m.

La inundación en Puerto Villamil

El día 11 de enero de 1983, gran parte de la población de Puerto Villamil amaneció inundada a consecuencia del torrencial aguacero del día anterior. La precipitación registrada fue de 115.5 mm. Un total de 13 casas fueron afectadas por la subida del nivel del agua. Las familias respectivas se vieron obligadas a evacuar. Abandonaron sus habitaciones y solicitaron alojamiento tanto en casas particulares como en casas pertenecientes a instituciones del Estado. El Ilustre Municipio instaló un sistema de bombeo en una de las vías públicas, con el fin de expulsar el agua de la laguna hacia el mar. El porcentaje de pérdidas a causa de la inundación fue bajo. Murieron algunas palmeras y plantas ornamentales que se cultivan en los jardines.

Cabe destacar que en la laguna que se formó dentro del poblado de Puerto Villamil, los pescadores capturaban lisas de tamaño mediano, además capturaron camarones y jaibas (*Cronius sp.*) en poca cantidad. A estas últimas se las podía capturar en las vías públicas y en los patios de las casas. En la laguna del Cementerio se concentraron en grandes cantidades y por algunas semanas se aprovechó de este recurso.

El fenómeno de "El Niño" en Galápagos corresponde a una catástrofe natural. En la Isla Isabela personalmente creo que hubo un cambio ecológico en la laguna del Cementerio, pero la naturaleza va recuperando su estado normal.

FLUCTUACIONES EN LAS POBLACIONES DE AVES EN
QUINTA PLAYA, ISLA ISABELA, GALAPAGOS

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Resumen

Las condiciones oceánicas y climáticas presentes durante el Fenómeno de El Niño 1982-1983 influyeron sobre el tamaño de las poblaciones de aves residentes y migratorias en la playa y en la laguna de Quinta Playa, Isla Isabela. La alta precipitación aumentó el nivel del agua en la laguna, bajó la salinidad y disminuyó la cantidad de organismos que sirven de alimento a las aves. El cambio del ecosistema de la laguna y la falta de alimento son posiblemente las principales causas para que las aves residentes y algunas migratorias hayan salido de la laguna en esta época.

Los efectos de los cambios oceánicos afectaron a las aves marinas migratorias (*Larus pipixcan*, *Sterna maxima* y *Sterna hirundo*), especialmente *Larus pipixcan* pues se encontraron muchas aves muertas en la playa durante febrero y marzo 1983.

Summary

The changes in the ocean and in the weather during El Niño 1982-1983 affected the population size of resident and migrant birds on the beach and

in the lagoon at Quinta Playa, Isabela. The heavy rains resulted in an increase in water level of the lagoon and a decrease in the salinity. Simultaneously, food items for the birds became scarce. These changes in the lagoon ecosystem and the low food availability are probably the main reasons for the disappearance of resident and some migrant birds from the lagoon during this period.

The oceanic changes affected populations of marine migrant birds (*Larus pipixcan*, *Sterna maxima* and *Sterna hirundo*). *Larus pipixcan* was particularly affected as many dead birds were found on the beach during February and March 1983.

Introducción

Desde septiembre 1982 a junio 1983 se estudiaron los cambios en el número de aves residentes y migratorias de playa y laguna en Quinta Playa. El estudio coincidió con el Fenómeno de El Niño, de modo que los resultados reflejan los cambios poblacionales de las aves por los efectos climáticos y sus consecuencias.

Materiales y Métodos

Para facilitar el conteo y observación de las aves se dividió con estacas a la playa y a la laguna en 10 partes. La playa se dividió en 4 zonas de acuerdo a la marea: Zona 1 = dunas; Zona 2 = marea alta; Zona 3 = marea media; y Zona 4 = marea baja. De igual forma se dividió a la laguna pero de acuerdo a la profundidad, así: Zona 1 = lodo seco a húmedo; Zona 2 = de 0 a 5 cm; Zona 3 = de 5 a 20 cm; y Zona 4 = de 20 cm en adelante.

Las observaciones y censos de las aves se reali-

zaron con ayuda de binoculares (7 x 40). Los censos de aves migratorias fueron hechos 4 veces por semana debido a su constante movimiento entre la playa y la laguna. Para aves residentes de la laguna, los censos fueron hechos una vez por semana debido a que únicamente se desplazan dentro de la laguna. Se sacó un promedio mensual de los censos.

Se recolectaron muestras de arena en la playa y de agua y lodo en la laguna para determinar la clase y disponibilidad de alimento de las aves. Las muestras fueron filtradas en una red de plancton de malla de 1 mm.

Las observaciones sobre la ecología alimenticia de las aves en la playa y en la laguna se hicieron por períodos iguales de tiempo para cada ave (Sosa en preparación).

Se registraron periódicamente la precipitación y temperatura ambiente. También se registró la temperatura y salinidad del mar y de la laguna, a una profundidad entre los 50 a 80 cm en los dos sitios. La salinidad fue medida con un hidrómetro de gravedad específica. Las lecturas fueron convertidas a salinidad usando las tablas correspondientes (U.S. Navy Hydrographic Office, 1952).

Resultados

Quinta Playa está localizada en la costa sur de la Isla Isabela hacia el occidente de Puerto Villamil. Tiene una longitud de 2 km por 60 m de ancho, donde el 85% es arena y el 15% es roca. La laguna, a 60 m detrás de la playa y separada por las dunas, mide 1 km de largo (de Este a Oeste) por 100 a 300 m de ancho. Es una laguna de agua salobre que está parcialmente rodeada de 2 especies de mangle, arbustos de *Conocarpus erectus* y árboles de *Avicennia germinans*. En las orillas crece *Sesuvium portulacastrum*.

en forma de almohadilla. Las dunas están parcialmente cubiertas por *Ipomoea pes-caprae* que es una planta rastrera, y por Poaceas.

Recursos meteorológicos

La temperatura ambiente alcanzó los niveles más altos en marzo 1983 (min 24, max 33 grados C) (Fig. 1). Los promedios de la temperatura del mar durante el día no variaron, por lo que se muestra un solo promedio mensual (Fig. 1). La mayor temperatura en el mar fue 29 grados C, que se mantuvo desde febrero a junio. En la laguna las temperaturas del agua cambiaron considerablemente de acuerdo a la hora del día (Fig. 1). A las 12:00 horas se registraron temperaturas por encima de los 32 grados C.

La precipitación muestra un incremento desde diciembre 1982 (Fig.2). La mayor precipitación determinó la subida del nivel del agua en la laguna, de 38 cm en septiembre 1982 a 134 cm en junio 1983 (Figura 2), la máxima registrada en los últimos 14 años en Quinta Playa (A. Tupiza com. pers.). Como consecuencia se presentó una disminución de la salinidad en la laguna, de 33 por mil en septiembre a 10 por mil en junio (Fig. 2). En el mar la salinidad se mantuvo en un rango de 34 a 35 por mil durante el período de estudio.

Cambios físicos en la playa y en la laguna

El mar está siempre agitado en la costa frente a Quinta Playa, pero en enero 1983 la marea subió más de lo normal, igual que en mayo 1983 (vea el artículo de Wyrski). En la playa los cambios fueron evidentes, pues zonas que en septiembre tenían rocas fueron cubiertas de arena en febrero y nuevamente en junio las rocas estuvieron descubiertas.

La laguna creció más en ancho que en largo, extendiéndose hacia la orilla sur (playa), y llegó a cubrir todas las zonas de lodo seco donde acostum-

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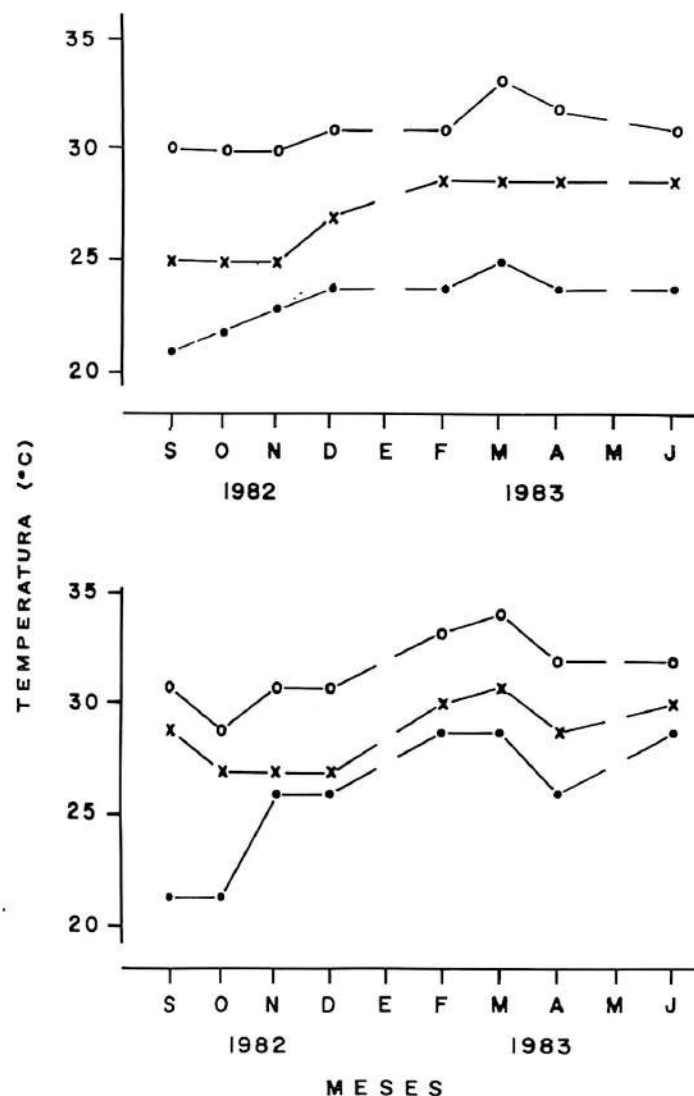


Figura 1. Promedios mensuales de temperatura del aire y del mar (arriba). Círculos abiertos y círculos oscuros = temperatura del aire, máxima y mínima, respectivamente. Equis = temperatura del mar. (Abajo) Promedios mensuales de temperatura de la laguna. Círculos oscuros = temperatura a las 0600 horas. Círculos abiertos = temperatura a las 1200 horas. Equis = temperatura a las 1700 horas.

braban descansar y dormir las aves. El agua cubrió gran parte de los islotes formados por arbustos de mangle que estaban hacia el centro de la laguna. En las orillas también inundó zonas de mangle, además de cubrir zonas de *Sesuvium portulacastrum*. La vegetación que fue cubierta por el agua empezó a descomponerse, amontonando mucha materia de consistencia pegajosa y pestilente tanto en las orillas como en zonas más profundas.

La vegetación de las orillas de la laguna y de las dunas, como los mangles, Poaceas y la rastrera *Ipomoea pes-caprae*, crecieron notablemente en cantidad y volumen.

Cerca de la laguna y a lo largo del sendero hacia Puerto Villamil se formaron pozas en sitios que estuvieron secos hasta diciembre; en estas pozas nuevas era común observar que aves residentes de laguna buscaban alimento, especialmente desde febrero a junio.

Invertebrados

Los invertebrados encontrados en la laguna varían en longitud de 1 a 4 mm y corresponden a un hemíptero, *Trichocorixa sp.*, que fue abundante en la Zona 2 (de 0 a 5 cm de profundidad) y en la superficie del agua. También 2 tipos de Crustáceos, ostrácodos y copépodos, que fueron abundantes en la Zona 3 (de 5 a 20 cm de profundidad) y en la Zona 4 (de 20 cm en adelante), se encontraron generalmente entre el lodo y las algas del fondo. El número de estos invertebrados bajó notablemente a partir de febrero (Figura 3).

En la arena de la playa el invertebrado más común es *Emerita cf analoga*. Se observó que la cantidad disminuyó durante el período de estudio y su ciclo de vida varió. Así, en septiembre y octubre 1982 se encontraron adultos y muchas hembras con

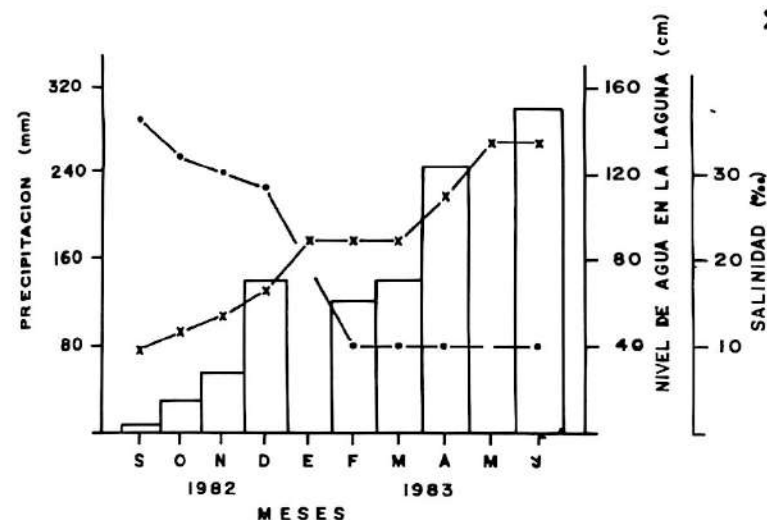


Figura 2. Promedios mensuales de precipitación, salinidad y nivel de agua en la laguna en Quinta Playa. Barras = precipitación, Equis = nivel de agua en la laguna. Círculos = salinidad en la laguna. No se midió precipitación y salinidad en enero y mayo. Nivel de agua en esos meses tomado por A. Tupiza.

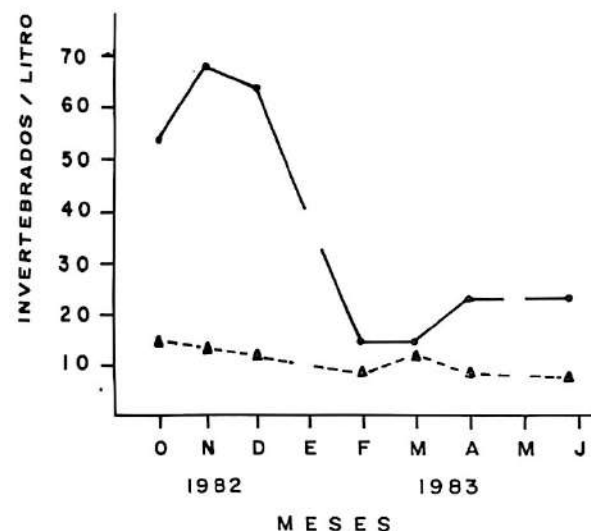


Figura 3. Cantidad de invertebrados por litro en la playa y en la laguna, Quinta Playa. Círculos = la laguna, triángulos = la playa.

huevos y de noviembre a junio se encontraron principalmente juveniles (Figura 3).

Insectos comunes en la laguna y sus alrededores como libélulas, hormigas, mosquitos y tábanos aumentaron en número notablemente.

Fluctuaciones en las poblaciones de las aves

De las 15 especies de aves estudiadas, 4 son residentes y 11 son migratorias (Tabla 1). Los resultados de los censos de aves residentes y migratorias se presentan en la Tabla 2 y Figura 4. El número de aves residentes en la laguna se mantuvo constante hasta diciembre. En cambio, desde febrero a junio salieron de la laguna en gran cantidad (Tabla 2, Figura 4). En contraste, el número de aves migratorias disminuyó durante los meses de estudio pero no de una manera brusca. No se tienen registros ni observaciones durante enero y mayo.

En los meses de marzo y mayo murieron 2 flamings (*Phoenicopterus ruber*) adultos debido a la escasez de alimento en la laguna; el ejemplar de marzo tenía su ala izquierda rota, incapacitada para volar.

Los patillos (*Anas bahamensis*) y tero reales (*Himantopus himantopus*) son residentes permanentes de la laguna, pero salieron desde diciembre. De febrero a junio llegaban a la laguna en busca de alimento, pero no permanecían en ella por mucho tiempo.

El número de ostreros (*Haematopus palliatus*) no pasó de 4 durante los meses de estudio. Usualmente se observó a una pareja alimentándose en la playa.

Los números de aves migratorias playeras y de laguna disminuyeron a partir de abril 1983. Las

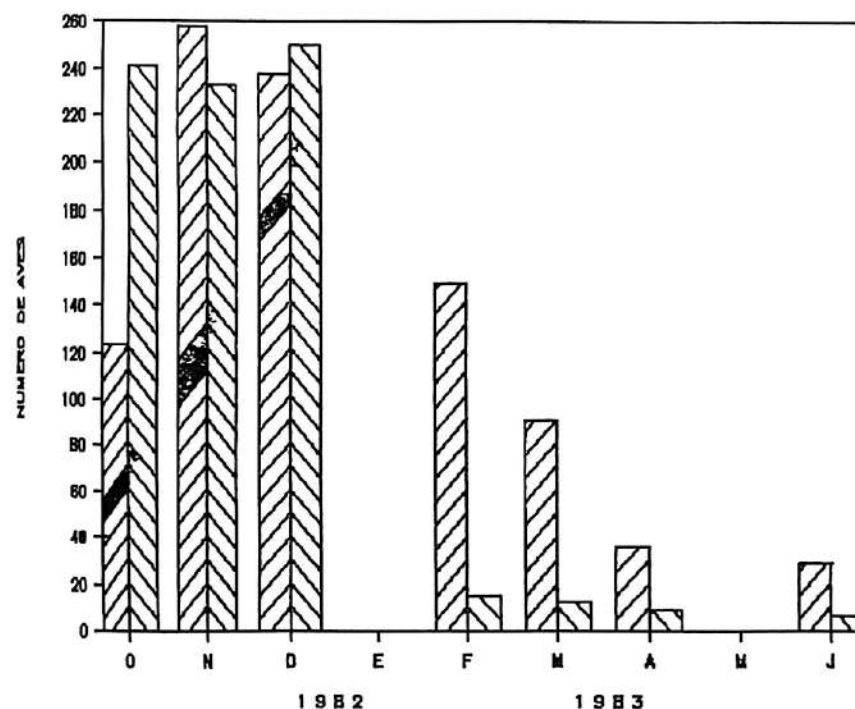


Figura 4. Promedio mensual de aves residentes y aves migratorias en Quinta Playa. Para cada mes la barra de la izquierda indica el total de las 11 especies migratorias y la barra de la derecha, el total de las 4 especies residentes. Para enero y mayo no se tienen registros.

Tabla 1. Sitios preferidos por las 15 especies de aves estudiadas en Quinta Playa, de octubre 1982 a junio 1983.

NOMBRE CIENTÍFICO	INGLÉS	NOMBRE COMÚN	ESPAÑOL	PREFERENCIA PLAYA LAGUNA
A. RESIDENTES				
<u>Phoenicopterus ruber</u>	Greater Flamingo	Flamingo		x
<u>Anas bahamensis</u>	White-cheeked Pintail	Patillo		x
<u>Haematopus palliatus</u>	Oystercatcher	Ostrero		x
<u>Himantopus himantopus</u>	Common Stilt	Tero Real		x
B. MIGRATORIAS				
<u>Squatarola squatarola</u>	Black-bellied Plover	Chorlito		x
<u>Charadrius semipalmatus</u>	Semipalmated Plover	Chorlitejo		x
<u>Arenaria interpres</u>	Ruddy Turnstone	Vuelvepiedras		x
<u>Heteroscelus incanum</u>	Wandering Tattler	Errante		x
<u>Cataptophorus semipalmatus</u>	Willet	Playero grande		x

Tabla 1. (continuación)

NOMBRE CIENTÍFICO	INGLÉS	NOMBRE COMÚN	ESPAÑOL	PREFERENCIA PLAYA LAGUNA
B. MIGRATORIAS				
<u>Eurenetes mauri</u>	Western Sandpiper	Playero occidental		x
<u>Erolia minutilla</u>	Least Sandpiper	Playero enano		x
<u>Crocethia alba</u>	Sanderling	Playero común		x
<u>Numenius phaeopus</u>	Whimbrel	Zarapito		x
<u>Limodromus griseus</u>	Long-billed Dowitcher	Agujeta		x
<u>Lobipes lobatus</u>	Northern Phalarope	Falaropo		x

primeras en salir fueron las que se alimentaban exclusivamente en la laguna; *Erolia minutilla*, *Eurenetes mauri*, *Limnodromus griseus* y *Lobipes lobatus*. Entre las playeras la primera en salir fue *Catoptrophorus semipalmatus*, el resto de playeras disminuyó su número hasta junio (Tabla 2, Figura 4).

Entre las especies residentes de la laguna, los flamings tienen sitios fijos en las orillas (hasta 30 cm), donde duermen. Los patillos también tienen sitios fijos para dormir, en las orillas sobre el lodo seco. Ambas especies mantienen grupos con un número de individuos por grupo más o menos constante. Los tero reales prefieren esconderse entre la vegetación de poca altura que crece a las orillas de la laguna, hacia el costado Norte de ésta; no se pudieron ubicar los sitios de dormir ni las parejas. La preferencia de sitios donde las aves desarrollan sus actividades alimenticias es diversa como se muestra en la Tabla 1.

Especies migratorias de laguna y playeras usan la laguna para descansar y dormir, prefieren orillas cubiertas de *Sesuvium portulacastrum* o de lodo seco. Los zarapitos (*Numenius phaeopus*), tuvieron una amplia zona de la orilla extrema oeste de la laguna, cubierta de lodo seco, que era su sitio de descanso.

Con los cambios en el nivel de agua de la laguna se cubrieron las orillas de lodo seco, así los patillos salieron de la laguna. Los zarapitos que usaban el mismo tipo de orillas que los patillos cambiaron su sitio de descanso hacia la arena húmeda de la playa. No se encontró anidación en ninguna especie residente en todo el tiempo de estudio.

Se llevó un registro de aves marinas muertas o agonizantes encontradas en la playa. Se registraron tanto aves migratorias como residentes (Harris, 1982) (Tabla 3).

Tabla 2. Resultados mensuales del promedio de aves residentes y migratorias en Quinta Playa, de octubre 1982 a junio 1983.

ESPECIE	OCT	NOV	DIC	MESES FEB	MAR	ABR	JUN
A. RESIDENTES							
<u>Phoenicopterus ruber</u>	162	185	240	11	4	2	1
<u>Anas bahamensis</u>	61	31	2	2	2	1	1
<u>Himantopus himantopus</u>	12	12	4	0	1	1	0
<u>Haematopus palliatus</u>	2	2	2	2	3	1	1
B. MIGRATORIAS							
<u>Squatarola squatarola</u>	2	3	3	2	2	3	3
<u>Charadrius semipalmatus</u>	5	4	4	5	6	1	2
<u>Arenaria interpres</u>	16	19	13	12	11	3	2
<u>Heteroscelus incanum</u>	3	0	3	1	1	2	1
<u>Catoptrophorus semipalmatus</u>	1	0	3	1	1	0	0
<u>Eurenetes mauri</u>	14	7	6	2	2	0	0
<u>Erolia minutilla</u>	5	13	10	5	2	0	0
<u>Crocethia alba</u>	25	29	28	36	32	16	6
<u>Numenius phaeopus</u>	31	106	72	77	31	11	14
<u>Limnodromus griseus</u>	4	7	4	4	2	0	0
<u>Lobipes lobatus</u>	15	67	87	1	0	0	0

Las especies marinas residentes no fueron tan severamente afectadas (Tabla 3). Se observaron hasta 6 gaviotas morenas (*Larus fuliginosus*), pero ninguna muerta durante los meses de estudio. Se observó hasta 20 pelícanos (*Pelecanus occidentalis*) anidando y con juveniles entre septiembre y noviembre, luego disminuyó su número. Los piqueros de patas azules (*Sula nebouxii*) fueron abundantes (hasta 60) en las zonas rocosas, entre septiembre y noviembre, luego disminuyó su número. Se encontraron 2 pingüinos (*Spheniscus mendiculus*) muertos. Entre las aves marinas migratorias, *Larus pipixcan*, fue la más afectada. En febrero se encontraron 30 aves de esta especie muertas en la playa.

Discusión

Los cambios climáticos ocurridos como consecuencia del fenómeno El Niño 1982-83 afectaron directamente al ecosistema de la laguna. Esto dio como resultado la salida masiva de las aves residentes y algunas migratorias (4 de laguna y una playera), que usualmente se alimentan en la laguna (tabla 2).

La alta precipitación ocasionó un aumento del nivel del agua en la laguna. Esto produjo una disminución de la salinidad. Los invertebrados que habitan en la laguna y que a la vez eran el alimento de las aves, en especial de flamings (Tindle y Tindle, 1978), decrecieron notablemente al bajar la salinidad (Fig. 3). La falta de alimentos obligó a salir a las aves residentes de laguna: flamings, patillos y tero reales, sobre todo durante febrero. El nivel elevado del agua eliminó los sitios de descanso de algunas aves y esto pudo influir en su salida. Además, influyó posiblemente en la reproducción de especies residentes de laguna, en especial de flamings, por lo que no se observó anidación en ninguna especie residente.

Tabla 3. Resultados mensuales de aves marinas muertas encontradas en Quinta Playa 1982-83

ESPECIE	MESES				
	OCT-DIC	FEB	MAR	ABR	JUN
A. RESIDENTES					
<u>Pelecanus occidentalis</u>	-	1	-	-	-
<u>Sula nebouxii</u>	1	-	-	1	1
<u>Spheniscus mendiculus</u>	-	2	-	-	-
B. MIGRATORIAS					
<u>Larus pipixcan</u>	-	30	3	-	-
<u>Sterna maxima</u>	-	-	3	-	-
<u>Sterna hirundo</u>	-	1	4	-	-

Durante septiembre a noviembre en las pozas de Villamil se contaron hasta 8 flamingos. En febrero mientras en Quinta Playa habían 11, en Villamil hubo 91 (A. Tupiza, com. pers.); conforme aumentaba el nivel de agua en las pozas de Villamil, estas aves salieron de allí quedando sólo 2 flamingos en abril 1983. Es posible que muchos de ellos salieron hacia pozas o lagunas cercanas.

La salida de las especies migratorias de laguna a partir de abril plantea dos posibilidades: 1) salieron por no encontrar alimento suficiente y sitios de descanso en la laguna, y 2) a partir de abril, algunas de ellas ya comenzaron a regresar a sus áreas de anidación en el Hemisferio Norte (Harris, 1982; Lévêque et al., 1966).

En el caso de las especies migratorias playeras, también disminuyó su número pero no en la proporción de las especies de laguna. Es posible que esta disminución se deba a que comenzaron a regresar a sus áreas de anidación en el Hemisferio Norte. La playa presentó durante el tiempo de estudio condiciones propicias para las aves, tanto en cantidad de alimento como en espacio físico disponible para recibir especies migratorias además de las especies residentes que normalmente se encuentran allí.

El comportamiento alimenticio de las especies residentes y migratorias no sufrió un cambio evidente (Sosa, en prep.), por lo que los efectos de El Niño no influyeron en su comportamiento alimenticio ni en sus preferencias alimenticias.

Las aves marinas migratorias, especialmente *L. pipixcan*, es posible que murieran debido a la incipiente cantidad de alimento disponible en el mar por los cambios oceánicos registrados durante el fenómeno de El Niño.

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PARTE IV

EFFECTOS EN LA FLORA
Y FAUNA TERRESTRE

EFFECTS ON TERRESTRIAL
FLORA AND FAUNA

THE EL NIÑO INFLUENCE ON
THE GALAPAGOS VEGETATION

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Summary

The influence of the El Niño phenomenon on the composition, structure and dynamics of Galápagos vegetation was studied in August 1983, about a month after El Niño conditions subsided. In 3 permanent quadrats on Santa Cruz and in 5 on Santa Fe, representative samples of arid zone and *Scalesia* zone vegetation were analyzed. Immediate effects recorded were minor changes in floristic composition and more pronounced changes in structure of the vegetation. The structural changes were caused by the death of many individuals of important woody species like *Opuntia* spp. and *Scalesia pedunculata*. Possible long term changes, which may result from the Niño event, include a different recovery pattern of arid vegetation on Santa Fe compared to previous years, and difference in recovery patterns between different types of *Scalesia pedunculata* dominated forest on Santa Cruz.

Resumen

El influjo del fenómeno El Niño sobre la composición, estructura y dinámica de la vegetación en Galápagos se estudió en Agosto de 1983, aproxima-

damente un mes después de que terminaron las condiciones del El Niño. En tres cuadrantes permanentes de la Isla Santa Cruz y en cinco cuadrantes en la Isla Santa Fe, se analizaron muestras representativas de las zonas de vegetación árida y de *Scalesia*. Los efectos inmediatos que se registraron fueron cambios menores en la composición florística y cambios más pronunciados en la estructura de la vegetación. Los cambios estructurales han sido causados por la muerte de muchos individuos de especies leñosas de importancia como *Opuntia* spp. y *Scalesia pedunculata*. Cambios a largo plazo que pueden resultar del evento El Niño incluyen un patrón diferente de recuperación de la vegetación en la zona árida de Santa Fe, en comparación con los años anteriores, y diferencias en los patrones de recuperación entre los diferentes tipos de bosque dominado por *Scalesia pedunculata* en Santa Cruz.

INTRODUCTION

Since 1966, changes in the Galápagos vegetation have been investigated by means of analyses of permanent quadrats representing various vegetation types. Over the years several biologists have participated in the studies, both in the analyses and in establishing new quadrats. Thus, today the vegetation on Santa Cruz, Santa Fe, Pinta, Santiago and Isabela is periodically investigated in this way. The studies have provided information on seasonal and long term changes in the vegetation; the emphasis of the studies has been on vegetational changes caused by feral goats, on successional processes (e.g. after the cessation of overgrazing) and on the dynamics of certain woody species like *Scalesia* spp. (References to papers, by various authors, dealing with the results of these studies may be found in Hamann 1981.

The periodic analyses of vegetation in permanent quadrats, carried out during 10 to 17 years, provide a basis for an investigation on the El Niño influence on the vegetation. The previously collected data

should allow, for example, to discern between those vegetational changes forming part of the normal pattern of fluctuations and successions, and those changes, which may be caused by the Niño phenomenon.

During the Niño 1982-83 heavy rains fell in the Galápagos for 9 months; lakes, rivers and waterfalls were formed in many parts of the islands, including some of the most arid regions. Desert-like areas became green, when an abundance of grasses, sedges, herbs and vines grew up. These immediate and general effects of the Niño were obvious, but did the Niño phenomenon initiate any long term changes in the composition, structure and dynamics of the Galápagos vegetation? Although it is too early to distinguish clear long term effects, certain trends may be suggested.

In August 1983, about one month after the Niño rains stopped, I had the opportunity to visit the islands and to analyze in detail the vegetation in 5 permanent quadrats on Santa Fe and in 3 on Santa Cruz. This report consequently, deals only with a part of the Galápagos vegetation, namely, the arid zone vegetation on Santa Fe and southern Santa Cruz, and the *Scalesia* zone vegetation on southwestern Santa Cruz. More general aspects of El Niño effects on the Galápagos vegetation are dealt with in the article by Luong & Toro (this volume).

SANTA CRUZ

Arid Zone Vegetation

On Santa Cruz 2 permanent quadrats close to the Charles Darwin Research Station were established in 1966 and have since been examined periodically. The vegetation in these quadrats is representative of the arid zone vegetation (Wiggins & Porter 1971), or more specific, of the microphyllous dry season deci-

duous steppe forest (woodland) encountered at lower elevations on south Santa Cruz (Hamann 1979a & 1981). In this vegetation, shrubs and small to large trees often form dense and thorny vegetation. Among the conspicuous woody plants are *Opuntia echios* var. *gigantea*, *Jasminocereus thouarsii* var. *delicatus*, *Bursera graveolens*, *Croton scouleri*, *Scutia pauciflora* and *Acacia* spp. Quite a number of woody species have their main occurrence in this and similar arid vegetation types. In general, the herb cover is sparse.

Since 1966 some changes in the composition of woody plants have been recorded. "Bursts" of growth by *Croton scouleri* (in 1970) and *Parkinsonia aculeata* (in 1976) were recorded in one quadrat, but in general the vegetation appeared to be stable. Rather big differences in the composition of the herb cover were recorded from year to year during the period, which was interpreted as seasonal fluctuations (Hamann 1979a).

The general aspect of the vegetation in and around the permanent quadrats was notably different in August 1983 (compare Figures 1A & 1B). Herbs, grasses and sedges were found in abundance in areas usually devoid of ground cover. Most striking was the enormous amount of vines present. In August 1983 vines were much more conspicuous than during any previous year, both in terms of species numbers and in relative amount of vegetative matter.

Table 1 gives a summary of the changes recorded in the two quadrats close to the CDRS. The fate of the *Opuntias* was characteristic for the arid zone vegetation: One large individual had died and fallen thereby killing two small individuals. One plantlet, less than 2 years old, had also died. In the arid zone vegetation many individuals of *Opuntia* had fallen or were falling, because their roots had rotted (see Figure 2B). Excessive water in the

Explanation of Figure 1.

Figure 1A. Permanent quadrat A on Santa Cruz Island in March 1982. Young individuals of *Opuntia echios* var. *gigantea* are about 12 years old. Typical dry aspect of vegetation in the arid zone.

Figure 1B. The same place in August 1983. The younger *Opuntias* in the foreground were covered with vines, especially *Desmodium procumbens* and *Rhynchosia minima*. The older *Opuntias* in the background were covered with *Passiflora foetida* var. *galapagensis*.



Table 1. Summary of changes in vegetation in permanent quadrats A & B, Santa Cruz, from before to after the Niño 1982-83.

Opuntia echios var. gigantea:

Size of Individuals in March 1982	Number of Individuals	
	March 1982	August 1983
x > 5 m	1	Dead, fallen
3 m > x > 1 m	5	5 alive
1 m > x > 0.1 m	5	1 broken, but alive 3 alive 1 dead
0.1 m > x	2	2 dead
Total	13	9 alive No new individuals

Other Woody Plants:

(10 species)	43	37*
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Herbs, Vines, etc.:

	Number of Species	
	March 1982	August 1983
Permanent Quadrat A	6	13**
Permanent Quadrat B	4	10***

* See text for further explanation.

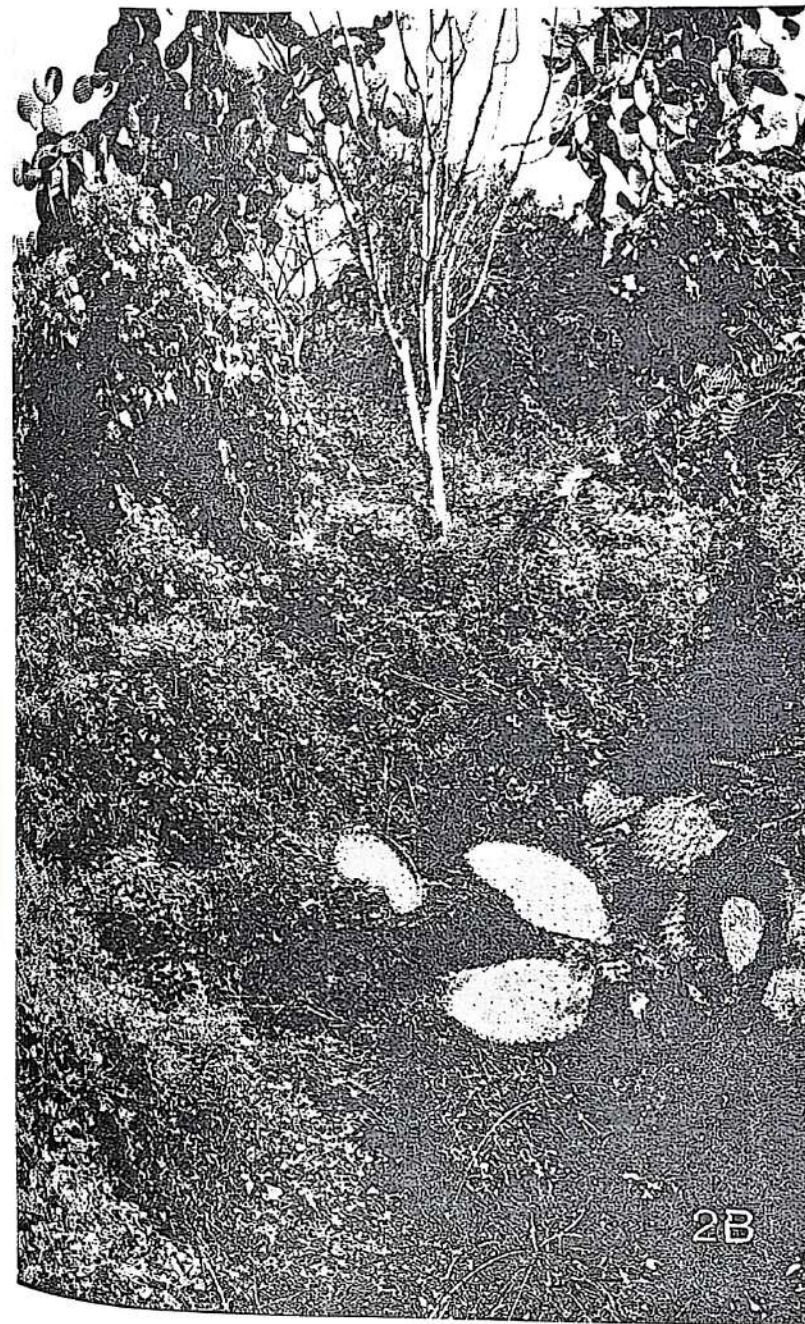
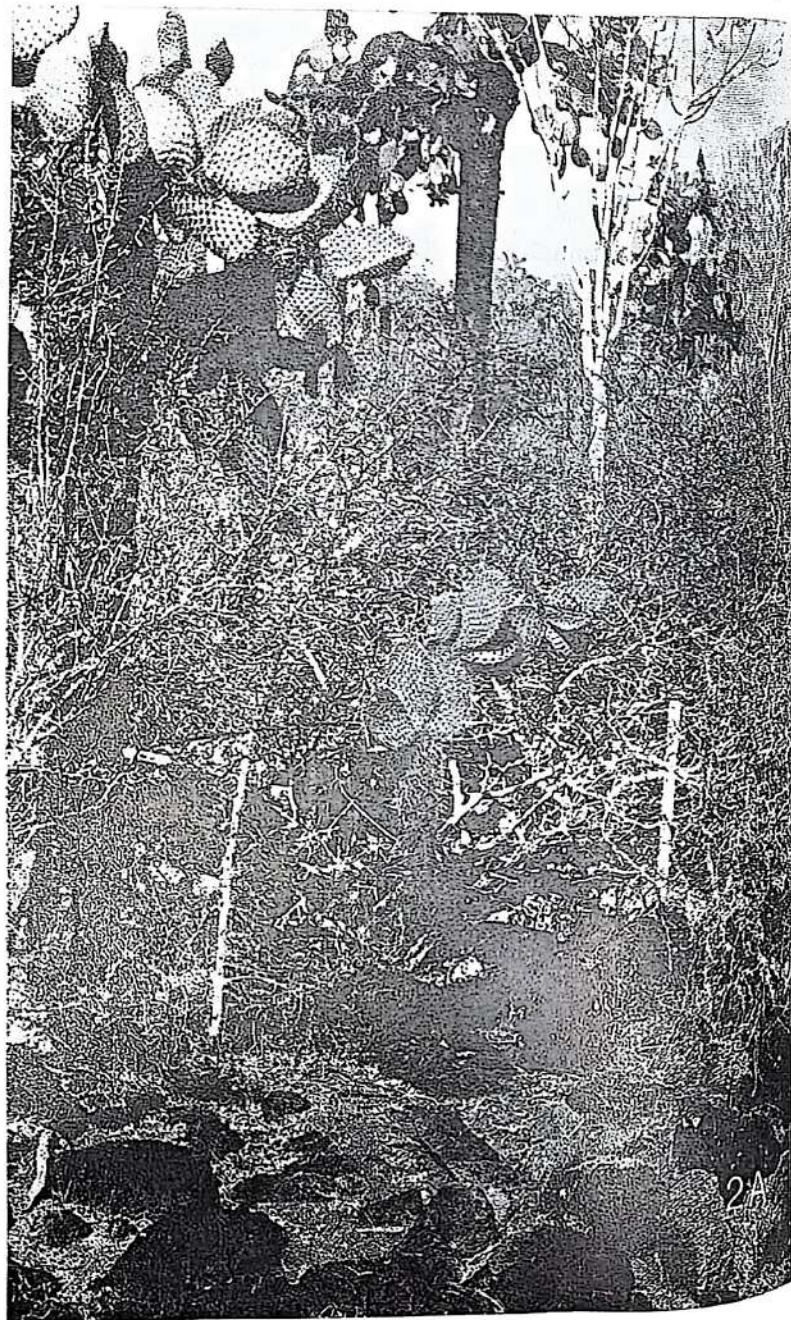
** Of these, Desmodium procumbens, Ludwigia erecta, and Passiflora foetida var. galapagensis, had never been recorded in the quadrat before.

*** Of these, Capraria biflora, Blainvillea dichotoma, Desmodium procumbens and Galactia striata, had never been recorded in the quadrat before.

Explanation of Figure 2

Figure 2A. Permanent quadrat A on Santa Cruz Island in March 1982. Typical vegetation with Opuntia echios var. gigantea, Bursera graveolens (background, center), Croton scouleri (background, to the right) and some leaf-bearing Acacias.

Figure 2B. Same place in August 1983. In 1983 one large Opuntia (growing outside the quadrat) had fallen into the quadrat. The small Opuntia and the shrubs were covered with vines like Desmodium procumbens, Rhynchosia minima and Passiflora foetida var. galapagensis.



soil, or perhaps, temporary flooding killed their roots during the Niño event. As the *Opuntias* were top-heavy with water already taken up in the pads, they just tumbled over when their roots could not support the weight any more. In addition, many smaller *Opuntias* died, probably because their roots were drowned, but also because they were over-shaded by the mass of vines growing upon them.

The examination of the *Opuntias* in the quadrats showed that practically no growth had taken place in $1\frac{1}{2}$ years, and that fruiting had been sparse. In general, it appears that the *Opuntia* cacti suffered during the Niño year, but their capacity for vegetative reproduction may turn out to be an important factor for the species to persist in great numbers. In many places pads from newly fallen *Opuntias* had, in August 1983, been able to root, thereby establishing new plants in place of the dead one. This is a common phenomenon for the *Opuntias*, which is not just restricted to Niño years. It is sometimes possible to trace the circumference of one fallen, long dead, large individual by the numerous plantlets growing from rooted pads.

Besides *Opuntia*, 10 other woody species are growing in the 2 quadrats. Some individuals had died during the Niño, and very few new plants were observed, but the decrease in numbers was not larger than that observed during previous examinations. However, individuals of *Parkinsonia aculeata* had grown much more than during any previous period of their life. Some of the *Parkinsonias* had, from March 1982 to August 1983, grown about 2-2.5 m, almost doubling their height.

The most apparent difference between the vegetation in the quadrats immediately after the Niño compared to previous years was the abundance of herbs and vines. Table 1 lists those species which had not been recorded in the quadrats before, i.e. in 17

years. Particularly noteworthy was *Ludwigia erecta* with numerous individuals reaching heights of 4-5 m. Usually *Ludwigia erecta* is found in shallow depressions at higher elevations, but in August 1983 it was very conspicuous in many places in the arid zone close to shore. The vine *Desmodium procumbens* was also extremely abundant, together with such species as *Rhynchosia minima* and *Passiflora foetida* var. *galapagensis*, which both are common members of the arid zone vegetation. The abundance of herbs, grasses, sedges and vines covering large areas suggests that a large seed reserve had been mobilized from the soil.

Scalesia zone vegetation

One permanent quadrat close to the "Caseta" in the Tortoise Reserve on Santa Cruz was established in 1970 and has since been examined periodically. The vegetation in the quadrat is representative of the *Scalesia* zone vegetation, which in this area may be characterized as a micro- to mesophyllous mainly evergreen forest (Hamann 1979b & 1981). It is a mesophytic forest, which is fairly distinctly stratified into a tree layer, a shrub layer and a herb layer. Many epiphytes and some vines are common. The tree layer is generally composed of *Scalesia pedunculata*, *Psidium galapageium*, *Zanthoxylum fagara* and, in places, *Pisonia floribunda*. The shrub layer is dominated by *Psychotria rufipes* and *Tournefortia rufo-sericea*. The herb layer is usually closed and dominated by mainly perennial species, while the annuals are few.

Examinations of the vegetation in the quadrat since 1970 have shown that the number of species and of individuals change during the years. The *Scalesia* trees display a characteristic pattern of growth and survival. Their mortality appears to be high during the first 3-5 years of life, whereafter it decreases,

but in general, *Scalesia* trees rarely become more than 15 years old (in this part of the island, at least). It was suggested (Hamann 1979b) that the *Scalesia* trees are pioneer or early successional trees that are able to persist as dominant members of the vegetation by rapid invasions of forest gaps, fast growth, early maturity and effective short distance dispersal. An important factor for the success of the *Scalesia* trees appears to be that only few species of late successional trees are present.

In August 1983 the general aspect of the vegetation in the *Scalesia* forest had altered considerably. The structure of the forest seemed to have changed. A large part of the *Scalesia pedunculata* trees had died and had fallen, so the number of large trees in the forest was drastically reduced. Furthermore, as in the arid zone vegetation, an abundance of vines covered much of the shrub and tree layers; the most abundant were *Stictocardia tiliifolia* and *Passiflora colinvauxii*, which are both common members of the *Scalesia* zone vegetation.

The permanent quadrat exemplified this different aspect (Table 2). The *Scalesia* stand in the quadrat was reduced to only 2 surviving individuals (trees of all age classes had died, including young ones), while only 2 seedlings less than 1½ years old had established themselves. Among the shrubs and herbs no species were recorded which had not been noted before in the quadrat. Actually, the number of herb species was lower than at previous examinations. Apparently such usually common species as *Salvia occidentalis*, *Pilea baurii* and *Blechnum brownei* were not doing well under the Niño conditions and the shade and competition presented by vines like *Stictocardia tiliifolia*.

Judging from a survivorship curve of the *Scalesia pedunculata* stand in the quadrat, it is not surprising that trees older than 10 years died;

Table 2. Summary of changes in a stand of *Scalesia pedunculata* in permanent quadrat G, at the 'Caseta', Santa Cruz, from before to after the Niño 1982-1983.

Scalesia pedunculata

Age of individuals in March 1982	Number of individuals	
	March 1982	August 1983
a > 10 years	5	4 dead 1 dying
10 years > a > 6.5 years	6	2 alive 4 dead
6.5 years > a > 2 years	1	1 dying
2 years > a > 1.5 years	5	5 dead
total	17	2 alive 2 dying Plus 2 seedlings < 1.5 years old

this could be expected to happen soon anyway. However, a larger proportion of younger trees died than should be expected under usual conditions. When comparing the quadrat with the vegetation of the surrounding forest, where many trees had died, it seems reasonable to ascribe this increased mortality to the effects of the Niño. The soil is rather shallow in many parts of the forest, and the *Scalesia* trees have a fairly weak root system, so the combined effects of the soil becoming waterlogged and the occurrence of thunderstorms, which were frequent during the Niño event, could account for the death of many trees.

SANTA FE

Arid Vegetation on the Opuntia Plains

The typical vegetation on most of Santa Fe is dry season deciduous steppe forest (woodland); it is prevalent on the rather flat plains or valleys situated between the east-west running ridges (barrancos). *Opuntia echios* var. *barringtonensis* and *Bursera graveolens* are the only trees in this vegetation, while a number of shrubby species, such as *Cordia lutea*, *Lantana peduncularis*, *Castela galapageia* and *Encelia hispida* form an unusually open shrub layer. The ground may be covered with vegetation (grasses and sedges are abundant) or it may be bare.

In 1971 the National Park Service succeeded in eliminating feral goats on Santa Fe, and during 1972 and 1973, six permanent quadrats were established on the island. They have since been examined periodically, and a regeneration of the vegetation has been recorded (Hamann 1979a). The number of individuals of woody plants in the quadrats has in general, increased. During the first 5 years after the elimination of goats it appeared that only about half of the woody species growing on the island actually increased in numbers. The other half did not participate in the revegetation. It was especially the shrub species, which increased in numbers while seedlings of *Opuntia* and *Bursera* were extremely rare. However, from about 1977, seedlings of these two species appeared in numbers, mostly in sheltered places, e.g. in shade beneath other plants or between lava boulders. Thus, the rate of regeneration of the vegetation on Santa Fe seemed to increase from 1972 to 1982.

Five of the 6 quadrats were examined in August 1983, and the vegetation in 4 of them may be regarded as representative of the prevalent dry season deci-

Explanation of Figure 3

Figure 3A. Permanent quadrat 2 on Santa Fe Island in October 1977. Typical open aspect of the vegetation with *Opuntia echios* var. *barringtonensis* and some low, dry shrubs. In the middle is one large, prostrate *Castela galapageia*.

Figure 3B. The same place in August 1983. Shrubs like *Cordia lutea* (to the left) and *Lantana peduncularis* were flowering and grasses covered the ground.

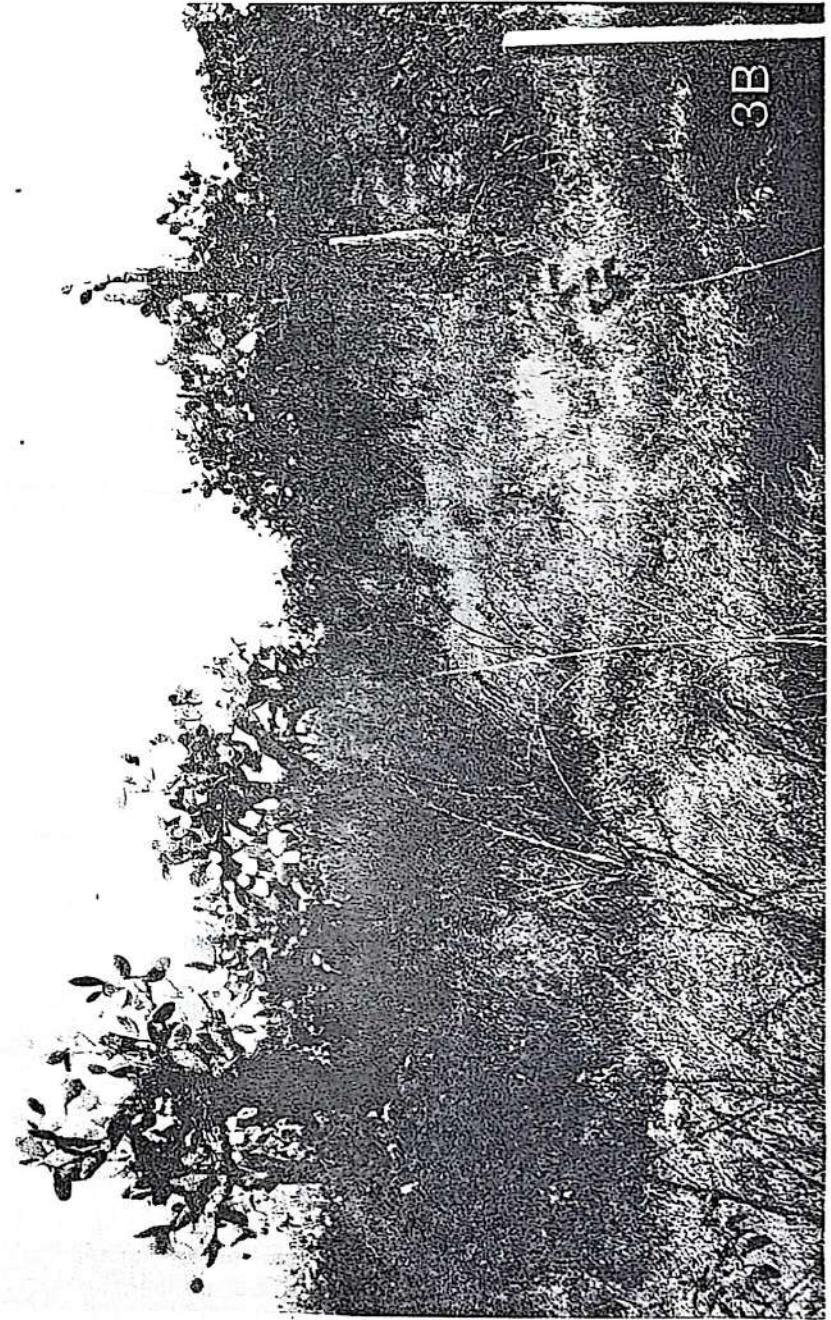
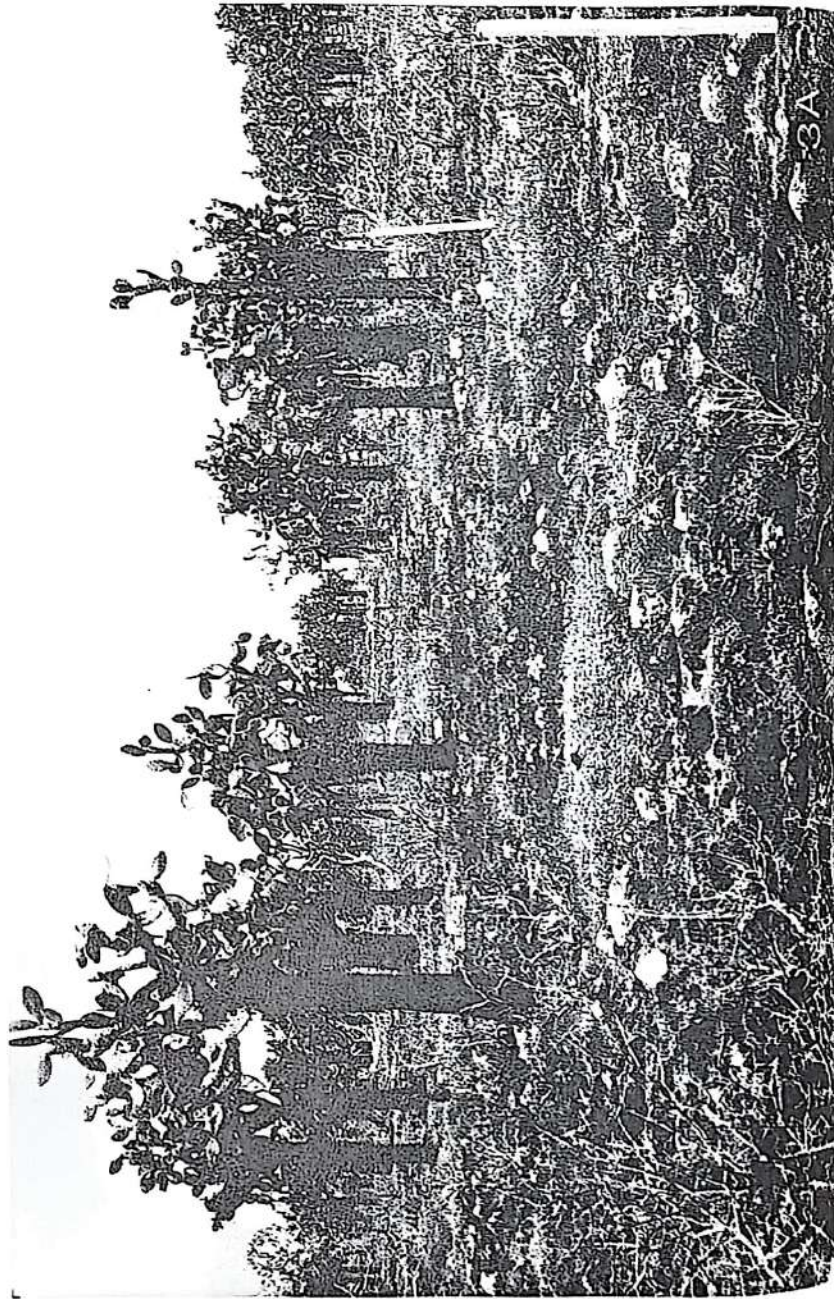


Table 3. Summary of changes in vegetation in permanent quadrats 2, 3, 5 & 6, Santa Fe, from before to after the Niño 1982-83.

Opuntia echios var. barringtonensis

Size of individuals in March 1982	Number of individuals	
	March 1982	August 1983
x > 4 m	4	4 alive
0.5 m > x	6	6 dead
Total	10	4 alive
		No new plants

Bursera graveolens

x > 3.5 m	2	2 alive
1 m > x	4	1 alive 3 dead
Total	6	3 alive
		No new plants

duous vegetation types of the island. As in other usually dry areas of the archipelago, a general abundance of herbs, grasses, sedges and vines was obvious (see Figure 3). The fate of the woody species was also comparable to that seen in arid vegetation on Santa Cruz. The large *Opuntias* in the quadrats survived (Table 3), but outside the quadrats many dead and fallen specimens were observed. Furthermore, all *Opuntias* less than 0.5 m tall, which had appeared in the quadrats during the previous few years, had died as well as some *Bursera* plantlets. The cause of death appeared to be the same for the two species, namely waterlogging or flooding. It

Table 3. Continued.

Lantana peduncularis

Number of individuals	
March 1982	August 1983
ca. 115	ca. 150, including about 40 new plants

Other Woody Plants

4 species	62	56*
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Herbs, Vines, etc.

Number of species	
March 1982	August 1983
12	18**

* See text for further explanation.

** Of these, 2 had never before been recorded in any of the quadrats (*Crotalaria pumila* & *Bouteloua disticha*). Of the 18 species, 7 were recorded as new to the respective quadrat.

should be noted (Table 3) that the size class structure of both *Opuntia* and *Bursera* stands on Santa Fe is peculiar, being composed of large, old individuals and small, young individuals with no individuals of intermediate size and age present (compare with the *Opuntias* on Santa Cruz, Table 1). This is undoubtedly a result of the former presence of feral goats, which for a long time (at least 66 years) had grazed the island (Hamann 1979a).

As on Santa Cruz, some pads from large *Opuntias* that had fallen were rooting and establishing new plants, but no new seedlings of *Opuntia* or *Bursera*

were seen. The shrub *Lantana peduncularis* appeared to be favored by the amounts of available water during the Niño, since seedlings of this species were seen all over the island. The slight decrease in the number of other woody species was mainly caused by the death of some *Cordia lutea*. In one quadrat, a ca. 1 m deep lake was formed, which simply drowned the plants (Figure 4).

In the 4 quadrats (treated together) an increase in the number of herbs, etc. was recorded (Table 3). In general, the herb cover was much more abundant and conspicuous than during any previous examination of the quadrats. The appearance of species, which had not before been recorded inside the quadrats, indicates that a seed reserve had been mobilized from the soil.

Scalesia helleri vegetation

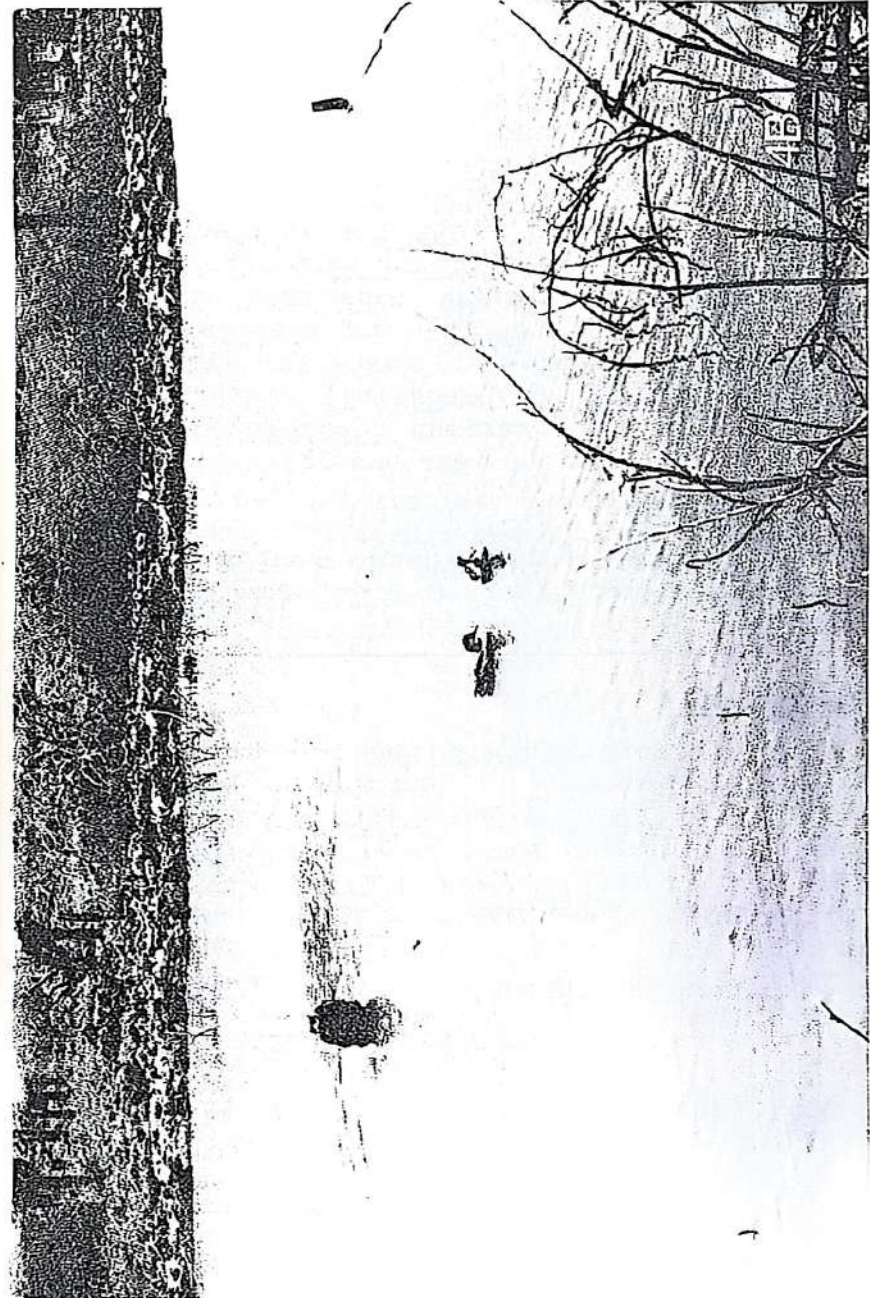
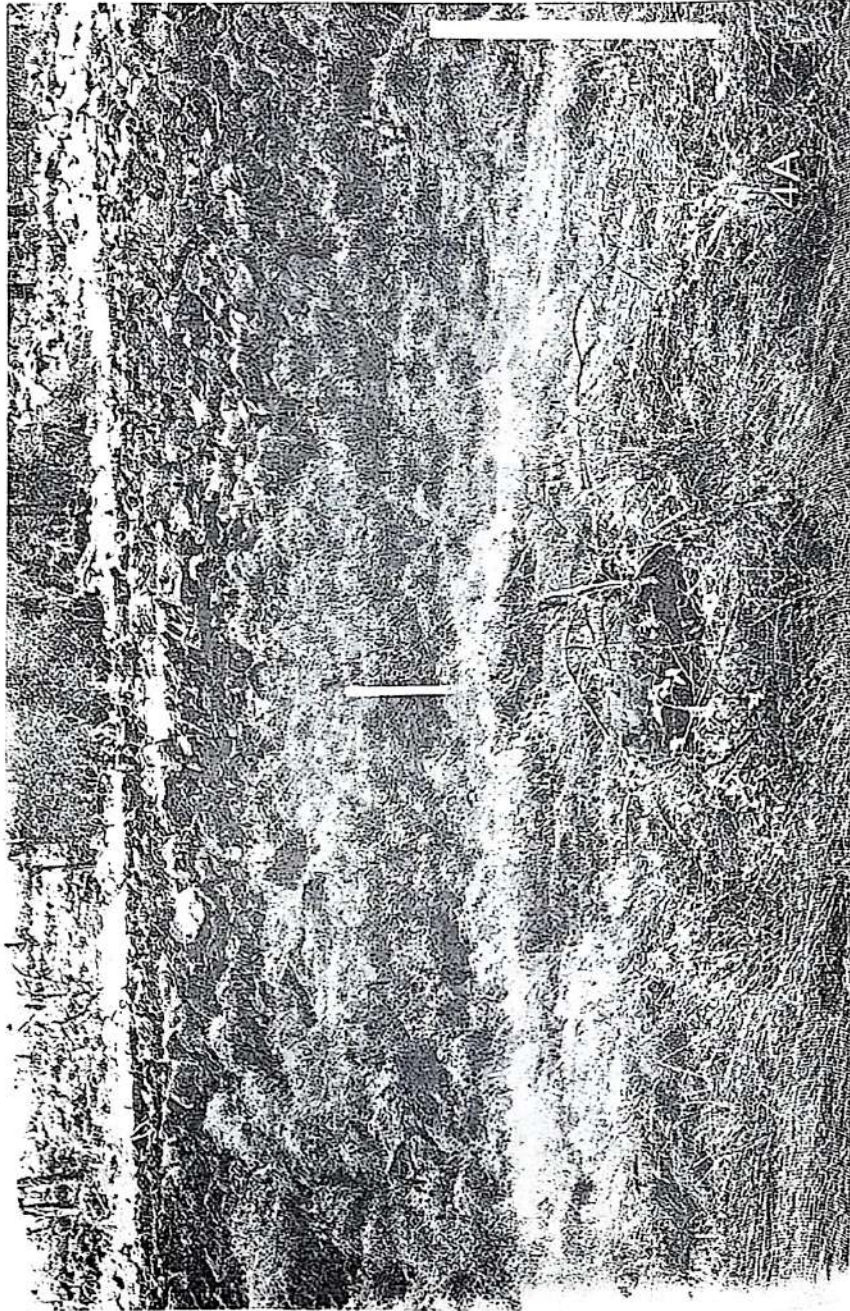
The landscape of Santa Fe is characteristic with east-west alternating barrancos and valleys. In many places, particularly near the coast, the steep barrancos are covered by a vegetation which may be described as mixed evergreen-dry season deciduous steppe scrub (Hamann 1979a). This vegetation is composed of shrubs or shrub-like small trees of which the evergreen *Scalesia helleri* and *Waltheria ovata* are dominant. *Cordia lutea* and *Lantana peduncularis* are very common too, while only few *Opuntia* and *Bursera* are found.

One permanent quadrat (no. 4) was established in 1973 on the near-coast barranco at the northeast corner of the island and a notable recolonization, especially by *Scalesia helleri*, has since been recorded (Hamann 1979a). It was suggested that *Scalesia helleri* is a cliff plant well adapted to short distance dispersal and that the recolonization of the barrancos by this species began when the grazing pressure from goats had been removed (Hamann 1979b).

Explanation of Figure 4

Figure 4A. Permanent quadrat 5 on Santa Fe Island in October 1977. The ground was covered with dry *Cyperus confertus* and in the background *Cyperus elegans* ssp. *rubiginosus*. In the middle is a low *Cryptocarpus pyriformis*.

Figure 4B. The same place in August 1983. From 1977 to 1982 only little change in the general appearance of the vegetation was recorded. However, note in Figure 4A the distinct line dividing the dark rocks in the depression from the white, lichen-covered rocks above. In 1983 the water level of the temporary lake reached this line, indicating that, infrequently, a lake is formed in this place, thereby preventing the lichens from establishing on the rocks in the depression.



In August 1983, it was evident that *Scalesia helleri* was one species that had been favored by the Niño conditions. On several barrancos, numerous seedlings were observed, as in the permanent quadrat (Table 4). From a survivorship curve of the stand of *Scalesia helleri* in the quadrat it was expected that some of the individuals more than 10 years old would have died since the last examination in 1982. Actually, half of the older individuals had died which is a slightly more than expected. The number of younger ones that had died is probably not much different from what should be normal, but the appearance of ca. 150 seedlings in the quadrat was very striking (the maximum number of seedlings recorded in any previous year was 38).

Table 4. Summary of changes in the stand of *Scalesia helleri* in permanent quadrat 4, Santa Fe, from before to after the Niño 1982-1983.

Scalesia helleri

Age of individuals in March 1982	Number of individuals	
	March 1982	August 1983
a > 10 years	12	6 alive 6 dead
8.4 years > a > 5.8 years	6	4 alive 2 dead
2.5 years > a > 1.5 years	1	1 dead
	Total 19	10 alive Plus ca. 150 seedlings < 1.5 years old

The ground in the quadrat is rocky and only few herbs have been recorded. During previous years the older individuals of *Scalesia helleri* have regularly been flowering and fruiting, and a large amount of the fruits were dropped immediately beneath the plants. The appearance of ca. 150 seedlings in the quadrat in 1983 was, without doubt, a result of the mobilization of part of this deposited seed reserve. Since the stand of *Scalesia helleri* grows on a steep barranco, the Niño rains did not result in flooding or waterlogging, but did provide plenty of water for the germination of seeds. In the quadrat (and outside, too) many seedlings of *Waltheria* and *Scalesia* were likewise observed.

Scalesia helleri displays a survivorship pattern similar to that of *Scalesia pedunculata*, so it may be expected that many of the ca. 150 seedlings will perish during the following years, but even a 20% survival will increase the density of this vegetation.

DISCUSSION

The immediate effect of the Niño 1982-1983 on the Galápagos vegetation were spectacular. When water no longer was a limiting factor for plant growth, a great number of species were able, not only to germinate and grow, but also to flower and fruit abundantly, both in arid and in humid vegetation types. Such species may be said to have reacted positively to the Niño conditions.

In the arid zone vegetation, non-woody species like *Desmodium procumbens*, *Cyperus elegans* ssp. *rubiginosus*, *Chloris virgata*, *Merremia aegyptica*, *Ludwigia erecta* and many others were much more conspicuous than during previous "normal" years. Among the woody species numerous seedlings of *Croton scouleri* (in places on Santa Fe) and *Lantana peduncularis*

showed a similar picture. Most striking was the appearance of hundreds of *Scalesia helleri* on barrancos on Santa Fe.

In the *Scalesia* zone vegetation on Santa Cruz, the vine *Stictocardia tiliifolia* and the sedge *Scleria pterota* were favored by the Niño. But in the humid habitats fewer species seemed to react positively to the Niño than in arid habitats.

Generally a large mobilization of a seed reserve in the soil took place, but since such species were able to fruit abundantly a new reserve undoubtedly was deposited during 1983.

Other Galápagos plants may be said to have reacted negatively to the Niño conditions. In the arid zone vegetation this was particularly the case for *Opuntia* spp. and, to a lesser degree, for *Bursera graveolens*. Waterlogging of the soil and flooding of depressions caused the death of many individuals, both large mature and younger, smaller ones. In the *Scalesia* zone vegetation on Santa Cruz the trees of *Scalesia pedunculata* were adversely affected because of the Niño. Not only in the Tortoise Reserve, but also in the forest above Santa Rosa many trees died and were still dying in August 1983, after the Niño had ceased.

Some of the immediate changes caused by the Niño point to possible trends for long term changes, in relation to structure and dynamics of the Galápagos vegetation.

The Niño conditions may have favored the colonization by plants not growing in the archipelago before. For example, tropical drift seed plants would appear to have a higher chance of successful immigration during a Niño event than during normal years. The extraordinary Niño conditions would facilitate not only transportation of such seeds and

fruits but also their establishment (e.g. by softening hard seed coats through prolonged soaking, Hamann, 1984). Additionally, elevated sea level observed during the Niño would permit tides to deposit such seeds further inland where they would be less likely to be disturbed by wave wash in normal years. Observations during the next years will reveal whether new species have been added to the flora, but until then it appears that the Niño did not cause a change in the general composition of the vegetation types. However, it did change the relative importance of the component species in some places: The structure of both arid and *Scalesia* zone vegetation seemed somewhat different in August 1983, compared to before the Niño. In the arid zone this was mainly caused by the death of many *Opuntias* and the abundance of vines, herbs, sedges and grasses. In the *Scalesia* zone it was mainly caused by the death of many *Scalesia* trees and the abundance of vines. These changes in structure suggest that the dynamics of the vegetation could be altered in some places. Apart from *Opuntia* the woody species in the arid vegetation on Santa Cruz (represented by the 2 permanent quadrats) survived in much the same proportions as before and no woody species displayed a large increase in numbers.

Effective vegetative propagation of *Opuntia* from fallen pads will presumably help the species to remain as a dominant. Thus, none of the immediate Niño effects would suggest long-term changes in this vegetation.

In the arid zone vegetation on Santa Fe recovery of vegetation has taken place during the last 10 years. At first this recovery was slow, but when *Opuntia* and *Bursera* seedlings started to appear, the rate of revegetation accelerated. The Niño event may have braked this recovery because many seedlings of *Opuntia* and *Bursera* died. On the other hand woody species like *Lantana pedunculata*

by the Niño. Provided some of the many seedlings of shrub species manage to establish, a general increase in density of vegetation should be expected which then means that germination and establishment of *Opuntia* and *Bursera* will be facilitated through the provision of shade. The study of the permanent quadrats during the next years may tell whether the recovery was slowed or accelerated by the Niño. However, the revegetation of the barrancos by *Scalesia helleri*-dominated vegetation will presumably be accelerated by the Niño event.

In the *Scalesia pedunculata*-dominated forests on Santa Cruz a general decrease in density of trees was recorded, both in the forest above Santa Rosa where *Scalesia pedunculata* practically is the only tree species present, and in the Tortoise Reserve (in and around the permanent quadrat), where other species like *Psidium galapageium*, *Zanthoxylum fagara* and *Pisonia floribunda* constitute an important part of the tree layer. This decrease was caused by the death of many *Scalesia* trees, while the other species were apparently not affected in a similar way.

According to Kastdalen (1982) and to my own observations, *Scalesia pedunculata* forest is able to recover very rapidly under certain circumstances. Kastdalen noted that "during the first five or six years of our stay it seemed that *Scalesia pedunculata* was disappearing. ...Then in 1944 and 1945 there were prolonged droughts of about four month's duration in each year. During these dry periods most of the underbrush died, and the damage was further increased by the wild cattle and donkeys which came up from the arid zone in search of food and moisture. This extensive damage to the underbrush, coinciding with prolonged droughts, made an ideal combination of circumstances for the regeneration of the *Scalesia* (it seems that *Scalesia pedunculata* will not seed properly except in dry weather). The succeeding "garúa" season showed a simply fantastic recovery of

the *Scalesia* forest." These observations are supported by the data collected from the permanent quadrat at the Caseta during 10 years. A previous clearing of undergrowth (by grazers, drought or both) seems to facilitate new starts of *Scalesia* trees.

In the *Scalesia* forest above Santa Rosa recovery may start after the next dry season (practically no other tree species are present). However, in the forest at the Caseta, where other tree species are present, the *Scalesia* recovery may take longer, especially because *Zanthoxylum fagara* trees, shrubs and the abundance of vines covering the ground may present unfavorable conditions for growth of young *Scalesia* trees, at least for some time. Consequently a rapid recovery of the *Scalesia* forest should not be expected in all places.

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CAMBIOS EN LA VEGETACION DE LAS ISLAS
GALAPAGOS DURANTE "EL NIÑO" 1982-1983

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Resumen

Los cambios en la vegetación de diferentes islas del archipiélago de Galápagos fueron estudiados durante los últimos meses de 1982 y durante 1983. En general, El Niño con sus grandes cantidades de agua fue la causa de graves erosiones, como la ocurrida en el camino de Bellavista a Media Luna en la isla Santa Cruz y como la erosión en la laguna Espumilla en Santiago. También causó la caída de árboles de *Opuntia* por una sobre absorción de agua en las islas Plazas, Santa Fe, Santa Cruz y otras. De igual forma, árboles de *Jasminocereus thouarsii* se cayeron en Santa Cruz; *Croton scouleri* se cayó en Rábida, Santa Cruz y Wolf; árboles de *Erythrina velutina* se cayeron en Wolf. Hubo dispersión de ciertas plantas como la planta introducida *Cucumis dipsaceus* en Española y de diferentes hierbas y lianas (*Nerrea aegyptica*, *Cacabus miersii* y *Sarcostemma angustissima*) en diferentes islas. Estudios adicionales de las comunidades vegetales se requieren para determinar cuales han sido los cambios permanentes que resultarán por los efectos de El Niño 1982-1983.

Summary

Changes in vegetation on different islands of the Galápagos Archipelago were studied during the

later months of 1982 and during 1983. In general, the enormous quantity of rainfall during the El Niño caused serious erosion of natural water courses such as observed between the town of Bellavista and Media Luna and at Espumilla Lagoon on Santiago. Large Opuntia trees, oversaturated with water, fell on Plazas, Santa Fe, Santa Cruz and other islands. Similarly, trees of Jasminocereus thouarsii collapsed on Santa Cruz; Croton scoulerii fell down on Rabida, Santa Cruz and Wolf; Erythrina velutina trees on Wolf were toppled. Dispersion of certain plants such as the introduced Cucumis dipsaceus on Espanola, and the grasses and lianas (Merremia aegyptica, Cacabus miersii, and Sarcostemma angustissima) was observed on several islands. Further study of these changes in plant communities are needed to determine if the 1982-1983 El Niño will produce any long-term changes.

Introducción

Desde fines de 1982 y durante 1983 visitamos varias islas del archipiélago de Galápagos para continuar con los estudios de la vegetación. Tales estudios están orientados hacia un programa a largo plazo de mapeo de la vegetación del archipiélago. Nuestro trabajo coincidió casi exactamente con el inicio de El Niño; por lo tanto, hemos anotado algunos de los efectos de este fenómeno en la flora galapagueña.

Materiales y Métodos

Este estudio está basado en las observaciones realizadas durante las visitas a diferentes sitios del archipiélago. En cada visita se determinó cualitativamente la abundancia de plantas de diferentes especies y la caída de otras debido al exceso de agua. Además, se determinó las nuevas áreas de distribución vegetal. Islas pequeñas pudieron re-

correrse en su totalidad o en una gran extensión. Para las islas grandes se observó solamente en determinados sitios. La dominancia de las especies se determinó de las listas de plantas registradas cada 50 m. Los sitios visitados y las fechas de las visitas se indican para cada isla:

Baltra, visitada el 1 y 2 de marzo de 1983. Las observaciones se hicieron en dos cuadrantes de 10 x 10 m (Luong, T.T., 1983b). Observaciones realizadas por C. Valle y E. Carriazo.

Plaza sur, visitada en dos ocasiones. Primera visita: abril 18 de 1983. Segunda visita: octubre 20 de 1983.

Seymour Norte, visitada el día 20 de octubre de 1983.

Daphne Mayor, visitada el 19 de octubre de 1983.

Pinzón, visitada del 10 al 18 de diciembre de 1982.

Rábida, visitada a finales de junio de 1983.

Bartolomé, visitada el 19 de octubre de 1983.

Fernandina, en esta isla visitamos Cabo Douglas del 24 al 31 de octubre de 1983. Caminamos por la costa y ascendimos solamente hasta 600 m de altura.

Marchena, visitada del 3 al 4 de agosto de 1983, del SE hasta la cumbre.

Genovesa, visitada el 5 de agosto de 1983, al NW y SE de Bahía Darwin hasta la laguna.

Darwin, visitada el 7 de noviembre de 1983 de la parte baja al NE.

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Wolf, visitada el 8 de noviembre de 1983.

Santa Fe, visitada desde el 30 de enero hasta el 4 de febrero de 1983.

Española, en esta isla visitamos Punta Suárez del 8 al 16 de julio de 1983.

Santiago, en esta isla visitamos Bahía Espumilla y su laguna el 19 de Abril de 1983 y por segunda vez el 18 de octubre de 1983. Bahía Sullivan se visitó el 19 de octubre de 1983.

Isabela, en esta isla se ascendió desde Puerto Villamil a Santo Tomás y a Sierra Negra y Cerro Azul desde el 8 al 16 de junio de 1983.

Santa Cruz, en esta isla se realizaron observaciones a lo largo del carretero que va desde el Canal de Itabaca hasta Puerto Ayora. Se visitó también El Chato, Media Luna y Santa Rosa.

San Cristóbal, visitada a mediados de mayo de 1983. Se recorrió el camino que va desde Puerto Baquerizo Moreno a El Progreso y hasta la laguna El Junco.

Resultados y Discusión

Cambios en la vegetación de las zonas bajas

En este trabajo se entiende por zonas bajas a las regiones del archipiélago con alturas inferiores a los 180 m sobre el nivel del mar. Dentro de esta altura se encuentran todas las islas pequeñas del archipiélago y la mayor parte de los sitios visitados por nosotros en islas más grandes. Como resultado de El Niño, las regiones secas del archipiélago mostraron una fisonomía vegetal diferente, con mayor ver-

dor y sobre todo con el predominio de ciertas plantas. Entre éstas cabe mencionarse a las hierbas y ciperáceas (Tabla 1).

Igualmente predominantes fueron las lianas y leguminosas (Tabla 1). Fue interesante observar que las lianas cubrieron por completo a grandes árboles de *Opuntia* y *Jasminocereus*, tales como los que se encuentran en las cercanías de la Estación Darwin.

Algunas plantas se beneficiaron con el agua. En las hojas de *Cryptocarpus pyriformis* se notó un crecimiento mayor, llegando al doble de lo normal. Plantas con hojas e incluso flores y frutos de *Lycium minimum*, *Grabowskia boerhaaviaefolia* y *Scutia pauciflora* contribuyeron al verdor de diferentes sitios del archipiélago, más que en años normales. Los árboles de *Opuntia* tuvieron dos floraciones en este año por efecto de la lluvia. *Jasminocereus thouarsii* en los alrededores de la Estación Darwin, se ramificaron mucho. Las medidas de 100 plantas en junio de 1983 mostraron que las ramas jóvenes habían crecido más de lo normal, con un crecimiento anual promedio de 50 cm o más (Luong y Toro, 1984). La gran cantidad de agua favoreció al Palo Santo (*Bursera graveolens*) el que mostró hojas por dos veces en este año. En la costa oeste de Pinzón, se encontró en flor a una "única y misteriosa" *Bursera* que creemos es la especie indígena *Bursera graveolens* (Luong, 1983a).

Algunas plantas fueron perjudicadas por el agua. Así, los árboles de *Opuntia* y *Jasminocereus* no sólo fueron cubiertos por lianas en muchos sitios del archipiélago sino que muchos de ellos se cayeron por la gran absorción de agua. En la visita a la isla Plaza Sur del 20 de octubre, contamos alrededor de 30 árboles grandes de *Opuntia echios* (de 4 m de altura) que se habían caído. En Santa Cruz y Santa Fe vimos también a muchas *Opuntias* y *Jasminocereus* que se habían caído. Por efecto de una absorción

Tabla 1. Dominancia de hierbas, ciperaceas, lianas, leguminosas y otras plantas (en alturas inferiores a 180 m).

ISLA	FAMILIA	ESPECIE
Baltra	Euphorbiaceae	<u>Ricinus communis</u>
	Gramineae	<u>Chloris virgata</u>
Seymur Norte	Gramineae	<u>Aristida subspicata</u>
	Leguminosae	<u>Phaseolus atropurpureus</u>
Daphne Mayor	Gramineae	<u>Chloris virgata</u>
		<u>Digitaria horizontalis</u>
	Solanaceae	<u>Cacabus miersii</u>
Pinzon	Gramineae	<u>Cenchrus platyacanthus</u>
	Loasaceae	<u>Mentzelia aspera</u>
Rabida	Loasaceae	<u>Mentzelia aspera</u>
	Convolvulaceae	<u>Merremia aegyptica</u>
	Leguminosae	<u>Desmodium glabrum</u> <u>Phaseolus atropurpureus</u>
Plaza Sur	Gramineae	<u>Aristida subspicata</u>
	Cyperaceae	<u>Cyperus andersonii</u>
Santa Fe	Solanaceae	<u>Cacabus miersii</u>
Espanola	Convolvulaceae	<u>Ipomoea habeliana</u>
Genovesa	Euphorbiaceae	<u>Chamaesyce</u> sp.
	Malvaceae	<u>Sida salviifolia</u>
	Convolvulaceae	<u>Evolvulus simplex</u>
Marchena	Leguminosae	<u>Rhynchosia minima</u>
Darwin	Solanaceae	<u>Lycopersicon cheesmanii</u>
	Convolvulaceae	<u>Merremia aegyptica</u>
Fernandina	Gramineae	<u>Aristida subspicata</u> <u>Bouteloua disticha</u> <u>Eragrostis</u> sp.
	Malvaceae	<u>Sida salviifolia</u>
	Convolvulaceae	<u>Ipomoea</u> sp.

desmedida de agua se cayeron también de 10 a 15 árboles de *Brythrina velutina* en Wolf, lo cual corresponde a la mitad de esta comunidad.

Croton scoulerii tampoco fue favorecido por las lluvias y muchos árboles murieron por exceso de absorción de agua en Rábida, Santa Cruz y en Wolf. En la Isla Wolf encontramos que en los bordes del sendero a la cumbre, alrededor de un tercio del total de árboles de *Croton* se había caído. Los árboles de *Croton* fueron también atacados por hongos y muchas plantas que crecían cerca de la costa murieron a causa del agua y de los hongos en noviembre de 1983. Es interesante anotar que debido a la abundancia de agua, las hojas de esta planta tenían un tamaño de aproximadamente el doble de lo normal.

El tomate, *Lycopersicon cheesmanii* apareció como dominante a diversas altitudes en varias islas y en algunos casos apareció como un registro nuevo (Tabla 2).

Erosión hubo en numerosas islas y debe haber contribuido a los cambios vegetales. Cabe mencionarse el caso de la laguna Espumilla (Santiago). En esta localidad la lluvia causó erosión, lo cual a su vez parece ser la causa de que la laguna se haya llenado de sedimento y de que sus aguas hayan salido al mar, secándose casi completamente. Esta circunstancia favoreció la expansión de la leguminosa *Cassia tora* y de *Cassia occidentalis* con sus flores amarillas, hasta cubrir aproximadamente la mitad de la laguna.

Cambios en la vegetación de las zonas altas

Las regiones altas de las islas tienen normalmente más humedad que las regiones bajas y su diversidad florística es también mayor. Por estos motivos ha sido más difícil detectar los cambios en la flora. En rasgos generales puede decirse que ciertas plan-

tas, especialmente plantas introducidas, fueron favorecidas por la abundancia de agua. Así en islas afectadas por la guayaba (*Psidium guajava*), esta planta fructificó en abundancia y creció notablemente. Del mismo modo en San Cristóbal, *Eugenia jambos* se dispersó y fue abundante en diferentes localidades entre El Progreso y la laguna El Junco, (alrededor de los 350 m de altura). Esta planta representa una amenaza para la planta endémica *Miconia robinsoniana* en esta isla.

En la isla Santa Cruz, a lo largo del carretero entre el Canal de Itabaca y Los Gemelos, fueron abundantes *Parkinsonia aculeata* y *Gossypium barbadense* con sus flores amarillas. El pasto elefante (*Pennisetum purpureum*) fue dominante entre Los Gemelos y Bellavista hasta un poco más abajo de los 150 m de altura. *Ricinus communis* fue dominante en los alrededores de Bellavista. En la reserva "El Chato", la leguminosa *Caesalpinia bonduc* se dispersó ampliamente y cubrió el sendero de turistas.

En Isabela encontramos que la leguminosa *Cassia tora* era dominante en varios sitios entre Puerto Villamil y Santo Tomás. A los lados del sendero entre Santo Tomás y Sierra Negra (hasta los 750 m de altura) fueron dominantes *Ricinus communis*, *Datura arborea* y *Piper aduncum*. En Cerro Azul la malvaceae *Sida salviifolia* fue abundante a lo largo del sendero hasta los 200 m, con un tamaño promedio de 1.5 a 2 m de altura.

La erosión también afectó a la vegetación de las partes altas de las islas, sacando el suelo y abriendo cañadas. Un caso notorio es la erosión entre Bellavista y Media Luna en la Isla Santa Cruz.

Nuevos registros de distribución vegetal

Los cambios en la flora y en las comunidades vegetales se determinaron por comparación con los

Tabla 2. Nuevos registros de distribución de hierbas, lianas, ciperaceas y leguminosas (en alturas inferiores a 180 m).

<u>ISLA</u>	<u>FAMILIA</u>	<u>ESPECIE</u>
Baltra	Malvaceae	<i>Sida salviifolia</i>
		<i>Sida spinosa</i>
	Compositae	<i>Porophyllum ruderale</i>
	Rhamnaceae	<i>Scutia pauciflora</i>
Seymour Norte	Gramineae	<i>Digitaria horizontalis</i>
		<i>Eleusine indica</i>
		<i>Trichoneura lindleyana</i>
		<i>Evolvulus simplex</i>
Daphne Mayor	Convolvulaceae	<i>Sarcostemma angustissima</i>
	Asclepiadaceae	<i>Cyperus andersonii</i>
		<i>Desmodium glabrum</i>
		<i>Commicarpus tuberosus</i>
		<i>Heliotropium angiospermum</i>
Bartolomé	Gramineae	<i>Chloris virgata</i>
		<i>Eragrostis ciliaris</i>
		<i>Trichoneura lindleyana</i>
		<i>Cacabus miersii</i>
Pinzón	Solanaceae	<i>Lycopersicon cheesmanii</i>
	Convolvulaceae	<i>Cuscuta gymnocarpa</i>
		<i>Sarcostemma angustissima</i>
Plaza Sur	Gramineae	<i>Eleusine indica</i>
		<i>Trichoneura lindleyana</i>
Santa Fe	Gramineae	<i>Eleusine indica</i>
	Cyperaceae	<i>Cyperus andersonii</i>
	Solanaceae	<i>Cacabus miersii</i>
	Convolvulaceae	<i>Cuscuta gymnocarpa</i>
		<i>Evolvulus glaber</i>
		<i>Ipomoea triloba</i>
	Asclepiadaceae	<i>Merremia aegyptica</i>
		<i>Sarcostemma angustissima</i>

Tabla 2. Continuación.

<u>ISLA</u>	<u>FAMILIA</u>	<u>ESPECIE</u>
Española	Gramineae	<u>Chloris virgata</u>
		<u>Paspalum conjugatum</u>
		<u>Eleusine indica</u>
	Convolvulaceae	<u>Evolvulus glaber</u>
	Cucurbitaceae	<u>Cucumis dipsaceus</u>
Genovesa	Malvaceae	<u>Sida spinosa</u>
	Gramineae	<u>Digitaria horizontalis</u>
	Convolvulaceae	<u>Ipomoea pes-caprae</u>
	Leguminosae	<u>Glactia striata</u>
	Gramineae	<u>Aristida divulsa</u>
Marchena		<u>Aristida repens</u>
	Cyperaceae	<u>Fimbristylis dichotoma</u>
	Leguminosae	<u>Neptunia plena</u>
	Gramineae	<u>Aristida divulsa</u>
Wolf	Convolvulaceae	<u>Cacabus miersii</u>
	Loasaceae	<u>Mentzelia aspera</u>
	Solanaceae	<u>Solanum nodiflorum</u>
	Malvaceae	<u>Sida spinosa</u>
Darwin	Convolvulaceae	<u>Ipomoea alba</u>
	Solanaceae	<u>Solanum nodiflorum</u>
Fernandina	Scrophulariaceae	<u>Galvezia leucantha</u>

trabajos de Wiggins y Porter (1971); Hamann (1981); van der Werff (1978); Schulter (1981); Grant (1977); y Grant y Grant (1980). La mayoría de los nuevos registros de distribución se refieren a las zonas bajas de las islas y a las islas pequeñas (Tabla 2). Las hierbas, ciperáceas, lianas y leguminosas aparecen como nuevos registros en numerosas islas.

Una planta exótica que representa un nuevo registro para Española es la cucurbitaceae *Cucumis dipsaceus*, comúnmente conocida como "huevos de tigre". Esta planta se dispersó por el sendero de turistas en Punta Suárez. En este sendero encon-

tramos también una planta de tomate que fue destruída.

En Bahía Sullivan (Santiago) encontramos dos plantas de sandía con una fruta madura cerca de la playa y una plantita de papaya (0.5 m de altura) en el sendero para turistas. Estas plantas fueron destruídas.

En Santa Cruz, la solanaceae *Browallia americana* con sus flores azules, aparece como un nuevo registro en diferentes localidades desde Bellavista a Media Luna, en Santa Rosa y en Los Gemelos.

En conclusión se puede afirmar que El Niño afectó a la vegetación de diferentes islas. Las aguas produjeron erosión y determinaron por tanto cambios en el suelo. Algunas plantas se beneficiaron de la abundante humedad. Estas crecieron e invadieron nuevas áreas y nuevas islas. Notables fueron los cambios en las zonas bajas de las islas, en donde predominaron y dieron nuevos registros las hierbas, las ciperáceas, las lianas, las leguminosas y otras plantas (Tablas 1 y 2).

Ciertas especies fueron en cambio afectadas por la abundante humedad. Las plantas de *Opuntia*, *Jasminocereus* y *Croton scoulerii* fueron afectadas de manera especial, pues la abundancia de agua que las plantas absorbían determinó que se cayeran. Las lluvias favorecieron finalmente a algunas plantas introducidas que crecieron y se dispersaron. Cabe citarse a *Cucumis dipsaceus* en Española y a varias hierbas y lianas en diferentes islas.

Es posible que efectos El Niño a lo largo de miles de años hayan contribuido a la expansión y asentamiento de diferentes plantas en sitios diversos del Archipiélago. De los nuevos registros que reportamos para este año, ¿cuántos resultarán en

nuevos asentamientos y en cambios de las comunidades vegetales? Estudios futuros de la flora nos ayudarán a comprender el significado ecológico y evolutivo de los cambios que se han operado en este período.

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EFFECTS ON CRYPTOGAMIC VEGETATION (LICHENS, MOSSES, AND LIVERWORTS)

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ABSTRACT

The extraordinary rainfall on Isla Santa Cruz and elsewhere wreaked havoc on the lichen flora almost everywhere. Crustose lichens on coastal rocks were worn away by unusually high tides or temporary waterfalls, or rotted by excessive moisture; foliose and fruticose lichens became waterlogged and fell or rotted, many host trees and living fences were undermined and fell, or the bark separated from the wood.

Mosses of the forest floor and along the flumes of springs were scoured away, and the subsequent excessive growth of herbs and vines deprived the substrate of light for their recovery. In the highlands the most common bryophytes flourished and many of the more uncommon or rare species, as well as the large foliose lichens, were swamped by them.

Comparisons with normal years are made, based on our experience with the flora in this area over a twenty-year period. Since such a phenomenon has never been observed before, it is impossible to predict the rate of recovery, which will vary with the species.

RESUMEN

La extraordinaria cantidad de lluvia recibida en la Isla Santa Cruz y en otras partes causó estragos en la flora de líquenes. Los líquenes costrosos de las rocas costeras fueron arrancados por las mareas altas o las cascadas temporales causadas por las lluvias, o se pudrieron a causa de la excesiva humedad; los líquenes foliosos y fruticulosos fueron anegados, por lo que se pudrieron y cayeron. Igualmente muchos árboles hospederos y cercas vivas fueron derribados, o la corteza se separó de la madera.

Los musgos del suelo del bosque y los que se encontraban en las orillas de los arroyos fueron arrastrados y el crecimiento excesivo subsecuente de las hierbas y enredaderas privaron a las criptógamas de su sustrato y de la luz para que se pudieran recobrar. En las partes altas, las briófitas más comunes se desarrollaron y cubrieron a muchas de las especies raras o poco comunes como los líquenes foliosos.

Se han hecho comparaciones con los años normales basados en nuestra experiencia de más de veinte años con la flora de esta región. Como un fenómeno de esta magnitud nunca antes se había observado es imposible predecir el rango de recuperación, el cual variará de acuerdo a la especie.

Lichens and bryophytes are very different types of organisms. Bryophytes are basically green plants that have a leafy or thalloid plant body; they reproduce by fragmentation or by the production of spores. They grow relatively rapidly and are able to colonize their habitats in the course of a season

or a year. They are relatively tolerant of liquid moisture and deep shade. Lichens consist of plant bodies (thalli) that are essentially fungal; algal cells are accommodated beneath the upper surface layers; the fungus destroys algal cells for its nutrition, but the algal cells reproduce more rapidly than they are destroyed. The lichens reproduce mostly by fragmentation; because they are a combination of different organisms that have evolved together, it is thought that most lichens must reproduce by fragmentation rather than by spore production. They are relatively slow-growing, some requiring only a few years to achieve their maximum size, others, mostly crust lichens on hard rocks, continuing to grow slowly for thousands of years. Lichens are relatively intolerant of liquid moisture and of deep shade.

Lichens and bryophytes form much of the Galápagos scenery, being a dominant aspect of the landscape on rocks and trees in the dry zones and the moist zones, respectively. Galápagos lichens are of great interest in plant geography because many of them are characteristic species of foggy coasts; their closest relatives occur in similar foggy environments on the coast of Chile and Peru. Many Galápagos lichens are endemic. The bryophytes of Galápagos are of less phytogeographic interest, and very few species are endemic. They are dominant in the moist upper areas of the higher islands.

The above introduction is extremely oversimplified, if not misleading, in view of the varied nature of the wide spectrum of types. For specific background information on the lichen and bryophyte vegetation of the Galápagos Islands the reader is referred to Weber (1966, 1976), Weber, Gradstein, Lanier & Sipman (1977), Weber & Lanier (1977, revised 1983), and Gradstein & Weber (1982).

Published observations having to do with the effects of non-man-caused environmental catastrophes on lichen and bryophyte floras, except those dealing with recent volcanic eruptions, are rare or non-existent. It seems to be taken for granted that lichens and bryophytes, even during normal seasons, do not undergo notable changes in their population sizes, that they are perfectly attuned to their environment and habitats, and that, except for man-caused air pollution in industrial areas, lichens and bryophytes are invariable and constant in the plant community.

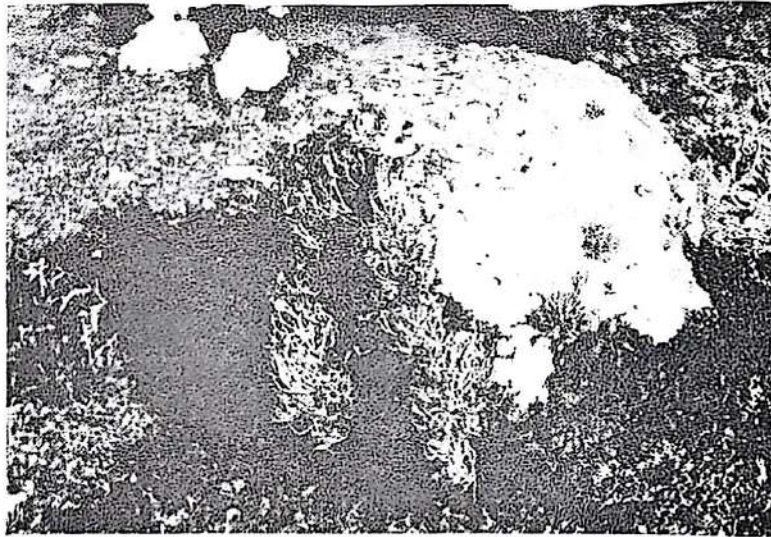
The senior author (hereafter referred to in the first person) first became aware that this might not be so when I once collected a large sample of the fruticose lichen Usnea on pine trees near a waterfall in southwestern Arizona. After I returned to my home institution and opened the packages, I discovered that I had collected a mixture of some five species but they had become hopelessly mixed and no longer were as distinctive when pressed as they had been in life. I returned to the same site three years later but found that the entire population had disappeared.

I later noted the same phenomenon with respect to some of the fruticose Ramalina species on the Galápagos Islands. In 1964 I was able to collect large quantities of at least nine different types of bushy Ramalina on the trees and shrubs lining the trail between Nelson's Hotel and the Station. These lichens evidently underwent a population crash shortly after, because in the subsequent twenty years I could find hardly any Ramalina in the identical transect. I consider this to be a normal population fluctuation, but once a crash occurs it may be many years before conditions are right for reestablishment.

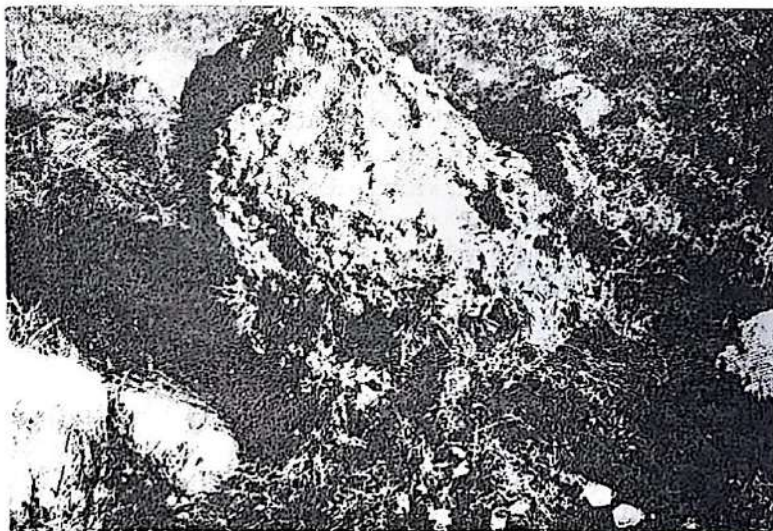
The Niño of 1983, however, affected almost all groups of lichens and bryophytes in one way or another, and some of the effects were so striking as to alter the gross visual aspect of the landscape. In December, 1983, I returned to the islands with three students on my fifth visit since the GISP expedition in January 1964 (20 years ago almost to the day). Our main mission was to collect a large set of an undescribed lichen growing on Cerro Azul, Isabela. Secondarily, we were interested in discovering anything that had been missed during previous expeditions, since each visit and the studies following it resulted in increased perspectives. Of course we knew that there had been an unprecedented Niño year, but we had not learned anything specific about its effect on the Galápagos.

Our first excursion was to a nearby beach where lava rocks formed a small jetty out into the surf, the type locality of Lecanora pseudopinguis and Buellia galapagona. To our surprise, we found that these species were hardly recognizable, having been soaked and eroded by salt water, leaving decorticated "ghosts". The magnificent displays of lichens on Plazas Islet, one of the showplaces of the islands, were similarly affected. Even the normally white terete thalli of the saxicolous Roccella galapagoensis were shrivelled and blackened. It was obvious that we might spend our time more profitably examining the profound effects of the Niño than hunting for new lichens.

Our observations were made purely fortuitously and not as part of a deliberate research project. As a matter of fact, after reconnoitering Santa Cruz from the Darwin Station to Mount Crocker, it was apparent that there would be little object in attempting to collect novelties, because the lichen and moss flora had been devastated. Instead, after some days in Santa Cruz, our party spent two weeks



Isla Plazas: boulder covered with healthy lichens in 1975. Note healthy ascending branches of fruticose *Roccella galapagoensis*



Isla Plazas: boulder showing degradation of lichens following the 1983 El Niño. Note the loss of color of the crustose lichens, indicating erosion of thalli, and stiff, shrunken branches of *Roccella*

circling Isabela and Fernandina contributing our help to the Darwin Research Station's special census of flightless cormorants and penguins. On this trip we were able to visit parts of Isla Santiago, Tagus Cove on Isabela, and various points along the coastline, where we had previously made collections. We succeeded in making the desired collections on Cerro Azul.

An event such as this Niño could not have been anticipated. Hence, the usual prerequisites for a scientific investigation such as prior establishment of picture points and detailed maps of colonies of lichens are lacking. Furthermore, the cost of expeditions rules out most kinds of continuous or repeated observations. And most unfortunately, there is no resident botanist on the islands who could be familiar enough with the cryptogamic flora to be able to carry on the research needed to follow the recovery process, which may take many decades.

In discussing the Niño's impact on cryptogams we should approach the situation from three standpoints: 1) the destruction of habitats and substrates on which the plants grow, 2) effects on the plants themselves, and 3) effects resulting from differential competitive success of one group with respect to another. These effects intertwine and are not always easily separated. It would have been useful to have been able to revisit all of the sites where we had collected cryptogams in the past, but this was impossible because of time and financial constraints. Therefore, most of the observations will have to do with Isla Santa Cruz, where we have had most of our experience.

Destruction of habitats and substrates

Two obvious effects of the Niño were the undermining of the shallow root systems of trees, and the

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deterioration of the trunks accompanied by separation of the bark. Many Opuntia and Jasminocereus trees fell over, their epiphytes with them. Pisonia was especially vulnerable; the collapse of the trunks was accompanied by a loosening of the bark, followed by sloughing and loss of substrate and lichens. Living fences of Jatropha curcas, a prime lichen habitat in the moist farming zone, became sodden, lost their leaves, the bark separated, the branches and eventually the trunks broke away. In the dry zone, Bursera and Piscidia appeared to be little affected, the trees remained standing and the bark tight, but the lichen flora on these trees was reduced to small numbers of hardly-recognizable types. Pyxine and Dirinaria cocoes survived better than the larger parmelioid types. Many genera normally present, such as Haematomma, Caloplaca, Buellia, were very rarely seen in good condition. On the other hand, endophloeoidal graphids, pyrenulas, Anthracothecium and coarsely granulose Chiodecton species seemed to be relatively healthy. Most lecanoroid crusts were unrecognizable to genus.

Cactus trees: the bark of the Opuntia tree is dry, thin, and the flakes so ephemeral that lichens never colonize them, but the pads of cacti, in suitable humid sites, often are as heavily encrusted with lichens of all types as the nearby rocks. In 1983, these pads were bare of lichens, showing only thin traces of crusts. The large spines of the areolae, usually substrate for the fruticose Roccella babingtonii, were bare of lichens. The spines themselves were reduced to short stumps coated with scurfy layers of the epiphytic alga, Trentepohlia.

The other tree cactus, Jasminocereus thouarsii, like the bark of the deciduous trees, is typically covered with lichen crusts. While these crusts were

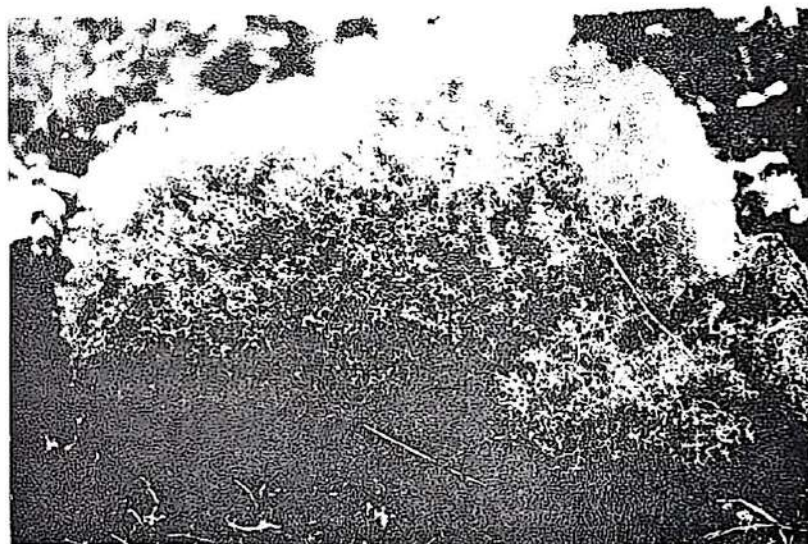
still evident, there was a great amount of deterioration of the cactus itself, including bark separation.

Mangroves: The trunks of Laguncularia and to a lesser extent those of Avicennia reaching above high tide level usually are colonized by thin thalli of Lecanora spp., red-orange Pyrenula cerina, and yellow Anthracothecium ochraceo-flavum. In 1983 I saw few lichens on these trees, presumably because they were destroyed by the unusually high tides and rains.

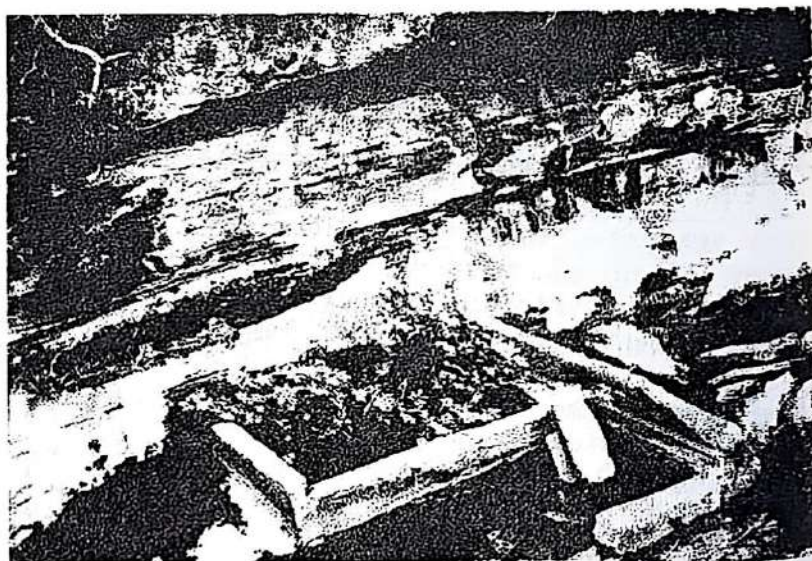
Evergreen Leaves: In the moist zone a number of lichens, mostly specific to leaves, occur on the evergreen foliage of Coffea, Eugenia jambos, and the evergreen fronds of Pteridium ferns. The Niño possibly enhanced growth of these epiphyllous lichens, for foliicolous lichens seemed to be more numerous on trees near Bella Vista than previously observed.

The Forest Floor: Relatively few moss species grow on the forest floor, but extensive patches of Racomitrium tomentosum, Hymenostomum breutelii, Hypophila involuta and H. microcarpa were present in former seasons. The forest floor seems to have been scoured clean of mosses, and the usually dry or intermittently flowing watercourses were heavily eroded, with large boulders moved downstream. Trails were often deeply eroded to bedrock, and the heaped lava hummocks were also scoured free. On trailside boulders only remnants of moss tufts remain, usually very moisture-favoring species of Fissidens and Philonotis.

Trails became choked by dense stands of weeds, particularly Kalanchoe pinnata, Plumbago scandens, Commicarpus tuberosus, and extensive vines of Passiflora foetida and Momordica charantia. Even away



Cladia aggregata, a fruticose lichen of the pampa, and similar lichens, were not seriously affected by El Niño



The flume of Conway Spring, on Isla Santiago; its wall, usually covered by mats of mosses, was scoured clean of mosses by El Niño Jan. 1984 photo)

from trails the understory became so dense as to exclude light from the normal moss habitats of the forest floor.

Springs: The few permanent springs on Galápagos support populations of rare subaquatic bryophytes. One spring in particular, Conway Spring on Isla Santiago, is noteworthy because the volcanic ash walls of its flume support an extensive colony of a very rare Caribbean moss, Gymnostomiella orcuttii. Most of this moss colony occurs around and directly above the cement trough built in the floor of the flume. Several other common mosses occur adjacent. The concentration of mosses diminishes beyond the area of influence of the water development, which evidently provides a continuously high relative humidity. The Niño of 1983 scoured out the flume, probably filling it to the brim with torrents which broke up the cement basin, scoured the flume walls clean of vegetation, and, in January, 1984, no water was running in the bottom. Only very small patches of Gymnostomiella remained, along with remnants of the other common associated mosses. Recovery of this colony will probably depend upon the revival of the source of water for the spring.

Effects on the organisms themselves

Effects of the Niño on bryophytes were relatively subtle. While the moss cover of forest floors was washed away, and rocks were denuded of mosses, the absence of mosses did not constitute conspicuous visual scars. Ground-dwelling liverworts and mosses of the pampa were replaced by algae sheets or shaded out by dense overgrowth of flowering plants. And the proportions of different species changed depending on their relative robustness and ability to swamp each other.

The effects on lichens, however, were striking, partly because of the destruction of the trees on which they grow. However, the lichens themselves also were affected independently of the loss of substrate.

Characteristically, a group of conspicuous dominant crustose lichens cover the surfaces of littoral rocks just above high tide mark. A combination of white (Arthothelium galapagosense), sulphur yellow (Lecanora pseudopinguis), cervine brown (Buellia galapagana) and red (Caloplaca sp.) crusts form mosaics on these surfaces. Typically these thalli are richly fruiting. The combination of heavy and protracted rains and overwashing salt-water of high tides caused profound alterations of the thalli. One of the lichenological show-places of Isla Santa Cruz is South Plazas Islet, where large boulders covered with lichens litter the upper slopes of the central area. In addition to the crustose lichens mentioned, yellow-green bushes of fruticose Ramalina species are usually abundant on the crowns of the boulders, and the chalk-white terete branches of Roccella galapagoensis arise in tufts from the underhangs of the sides of these boulders. Healthy Ramalina thalli are from 3 to 5 cm high; healthy thalli of Roccella are plump, and the branches typically curve upwards from near their bases to a height of over 10 cm.

The effects of the Niño on these various lichens are as follows. The excessive washing of the thalli evidently had several separate effects. As to the crustose lichens, the pigment of the yellow thalli, deposited as it is between the cell walls, has mostly disappeared. The soaking of the apothecial disks seems to have resulted in the loosening and sloughing away of the asci and paraphyses, leaving empty saucers. There seems to have

been substantial erosion of the cortex, making it difficult to distinguish the species and genera, which now are more or less similar, white "ghost"-thalli.

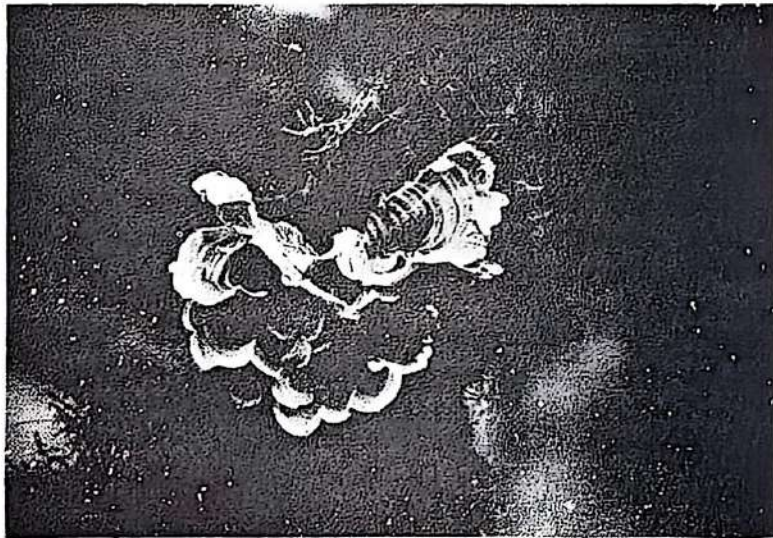
The Ramalina thalli, evidently very sensitive to waterlogging, have dropped away from the rocks, and the only thalli seen were a few minute ones less than 1 cm tall. The Roccella thalli were shrunken as if their medullary tissues had been reduced; the normally white cortex was a dull gray-brown, and the branches were stiff and straightened, generally all pointing downwards. The branches, furthermore, were not half as long as normal. The orange thalli of Caloplaca had all but disappeared.

From 1964 to 1975, low-lying lava boulders in the cactus forest behind the Darwin Station displayed a riot of lichen color, contributed by a rich assemblage of species and genera, including crustose and foliose types. Dominant were species of the genus Parmelia sens. lat., the pale yellow crustose Buellia glaziouana, and the bright yellow placodioid Pyxine pringlei. Following the Niño, no foliose or placodioid lichens survive. As on Plazas, the remaining crusts are a thin, nondescript white decorticated covering. On the side of the steep barranca, however, there are vertical, somewhat underhung faces of rock that support an extremely thin, somewhat purplish-gray crust of Roccellina phaea, a rare disjunct between Galápagos and the coast of Peru. These underhangs appear to remain dry throughout the worst of rainy seasons, and the thalli of this species seemed to be unaffected.

Life spans of foliose or umbilicate lichens are relatively short, to be measured in years or decades rather than the hundreds and thousands of years attributed to slow-growing crustose lichens of



A foliose lichen, Ramalina, usually abundant on twigs (1975 photo) was decimated by El Niño



Dictyonema montanum, a foliose lichen of the moist zone, was not seriously depleted by El Niño

siliceous rock habitats. Destruction of lichen thalli by the Niño probably never results in the extinction of species because only a small fragment of a thallus, consisting of a few fungal strands wrapped around a few algal cells, is enough to regenerate the plant. The speed at which this occurs, however, is open to question and must vary from species to species within very wide limits.

Foliose lichens such as Parmelia appear to have become waterlogged and rotted in place on the bark. Physcia, Dirinaria and Pyxine were affected differentially. Physcia, which is relatively loosely affixed to the substrate, was absent, while small thalli of the more tightly adnate Pyxine and Dirinaria survived. Since foliose lichens on bark are no older than their substrates, recovery of damaged thalli might be expected to be very rapid, while the replacement of destroyed thalli would depend on the occurrence of optimum conditions for dispersal of propagula from other sources, and for their subsequent development. Depending on the species, this might require only a few years to a few decades.

Presumably, special conditions are required for the germination and establishment of new thalli of fruticose lichens; they doubtless have finite life spans, and appear, flourish, and disappear depending on environmental conditions and age of the plant. Other species of Ramalina, such as the abundant pendent R. usnea of the Transition Zone, never seemed to vary in abundance until 1983, when so many of them were stripped from the trees.

Fruticose lichens were very adversely affected. Species of Ramalina, Usnea, and Roccella babingtonii, which commonly festoon the branches and trunks of the hardwood trees, were very hard hit. Roccella babingtonii, usually abundant on somewhat

moribund trees, evidently became waterlogged and fell away. Only a few wretched thalli were seen. Ramalina, likewise, was practically nonexistent in the dry zone, where at least a half-dozen species should be abundant. Ramalina usnea, usually extremely abundant in the Transition zone, was much less abundant than usual, and the pendent strands were shorter. The common bushy red-orange Teloschistes flavicans was found only a few times, as very depauperate individuals.

Crustose lichens on rocks and on bark were affected drastically and in a rather peculiar way. On the coastal rocks above the normal high tide mark there are three or four dominant lichens that are responsible for spectacular splashes of color, and whose thalli cover large areas: the sulphur yellow Lecanora pseudopinguis, the cervine brown Buellia galapagona, the orange-red Caloplaca sp. indet., and the chalk-white Arthothelium galapagosense. Their present appearance suggests that prolonged washing by fresh and/or salt water leached out the pigments of the Lecanora, which are deposited outside the cell walls. The Buellia was decorticated and severely eroded away. All species were reduced to nondescript faded remnants. The apothecia were generally empty of contents, leaving only the thalloid rims. This may be attributed to the fact that the asci and paraphyses of which the apothecial contents are composed imbibe water differentially, and that repeated swelling causes them to be ejected en masse from the disk.

Other saxicolous lichens as well as corticolous lichens also tended to be mostly non-fruiting and represented by nondescript white crusts, often lacking the normal cortical covering. The lichens were not completely destroyed and will undoubtedly regenerate from the remaining medullary tissue, but distinctions between crustose genera and species

were obscured by the damage. However, some crusts, particularly those which are endophloeoidal (under the epidermal layers of the bark) were not seriously affected, and those with normally unconsolidated cortices and ropy marginal hyphae, such as Chiodecton, seemed not to have been affected at all.

Species Competition

In the highlands "Brown Zone", where the branches of shrubs and trees are festooned with masses of liverworts and mosses, a change in the proportions of species was noted. The most dominant species of mosses, Zelometeorium patulum, and of hepatics, Frullania species, were as abundant, or probably more so, than ever, but the rarer mosses usually found on slender twigs, were absent. One got the impression that either the twigs on which they usually grow were moribund to begin with, and fell away, together with their delicate moss plants (Daltonia, for example), or the larger pleurocarpous mosses and hepatics simply overgrew everything else.

The large foliose lichens in the genera Sticta and Pseudocyphellaria were sparse, and the thalli seen were mostly rotted. This might have been caused by the fact that the mosses in which they were growing remained sodden for long periods of time, providing an intolerable ambience for the lichens. The basidiomycete lichen, Dictyonema montanum, was found in good condition, but in fewer numbers than usual. For some reason it did not show any signs of waterlogging. The Niño rains evidently encouraged the dominant corticolous mosses and hepatics, but either destroyed other species or caused them to lose out to competition. The cushion-forming moss, Groutiella mucronifolia was still present but not abundant, on horizontal branches, but other smaller species of Groutiella and Macromitrium were not seen.

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Conditions on the pampa reflected the Niño in the great increase of weedy species of flowering plants such as Jaegeria gracilis that mark the trails, but cryptogamic plant damage was spotty. The fruticose lichen, Cladina, appeared to be quite healthy, anchored as it usually is to shrub branchlets. The compressed earth of trails, usually covered by green sheets of various semiaquatic mosses and hepatics (Marchantia, Fossombronia, Riccia, Philonotis) were bare of these plants, which were replaced generally by slimy sheets of dark green algae--probably a competitive effect. parmelioid lichens, which are usually abundant on the exposed rocks, were absent. Sphagnum pools were well-stocked, indicating that the water level probably did not vary excessively on the pampa.

In general, the pampa on both Santa Cruz and Cerro Azul, Isabela, did not show much lichen destruction. Perhaps this is because the area is near or above the inversion layer and either did not receive as much rain as areas lower down, or the numerous deep crevasses carried off the water more quickly, or most likely, there was not the accumulation of runoff from above that resulted in the extensive scouring of terrestrial habitats farther downhill.

Conclusion

The Niño of 1983 on Santa Cruz Island destroyed many trees that serve for lichen habitats. Rock-inhabiting lichens were heavily damaged by water-logging and scouring by running water. General destruction of the surfaces of thalli rendered lichens nondescript and sterile. Pendent fruticose lichens and foliose lichens on bark became water-logged and fell away from their substrates. The forest floor was swept clean of bryophytes and lichens. Certain dominant bryophytes in the

highlands grew rampantly at the expense of smaller mosses and foliose lichens. On Isla Santiago the Conway Spring was scoured out, decimating a colony of a rare moss.

However devastating the effects of the Niño on the populations of bryophytes and on the physical structure of lichen thalli, we believe that the effects are temporary. There is no reason to believe that any extinctions have occurred or that recovery will not eventually restore the vegetation to its former abundance and vigor. However, given the destruction of substrates and the lack of our knowledge as to the time required for thallus regeneration, a century or more may well elapse before we will again see the Galapagos as it was in 1964.

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EFFECTS OF EL NIÑO ON GIANT TORTOISES
AND THEIR ENVIRONMENT

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Summary

Of the Galápagos fauna, giant tortoises (*Geochelone elephantopus*), the one large native herbivore in the islands, were perhaps the least affected either positively or negatively by the 1982-83 El Niño event. They are unique among the fauna in their ability to survive many different extremes in weather conditions with negligible effect on their populations. The feeding ecology and daily activity patterns of a domed race on Santa Cruz and a saddle-backed race on Pinzón were studied from June 1981 through September 1983. The onset of El Niño effected a mass migration of tortoises on Santa Cruz from higher elevations to lowland areas. Their daily activity patterns did not change substantially, although with the extremely great abundance of vegetation resulting from El Niño, they did spend a greater percentage of daylight hours feeding. Pattern of water collection and flow of flood waters of El Niño appeared to be the ultimate factor delineating habitat types in the Transition/*Scalesia* Zone of Santa Cruz around the Caseta and El Chato. Other important effects of El Niño on the vegetation on both Santa Cruz and Pinzón were an overall increase in the number of species, a large increase in abundance of vines, and the destruction of *Opuntia*. Studies on Pinzón showed results similar to those on Santa Cruz,

including an increase in time spent feeding by tortoises and a more varied diet resulting from the increase in number of species. There was no change in tortoise distribution on Pinzón during El Niño. Finches were seen cleaning ticks off tortoises frequently during the dry season prior to El Niño, but seldom during the wet season. The great rivers of the 1982-83 El Niño suggest a way in which tortoises originally dispersed among the islands, following the arrival of the first tortoises from the continent. Their longevity, slow metabolic rate, and low mortality rate for adults enable tortoises to "wait out" periods of extreme weather conditions which may cause "bottleneck" situations for other species of the fauna of the Galápagos Islands.

Resumen

De entre toda la fauna galapagueña, las tortugas gigantes (*Geochelone elephantopus*), que corresponden al único herbívoro grande de las islas, fueron tal vez las menos afectadas sea positiva o negativamente por el evento de El Niño 1982-83. Ellas son únicas entre la fauna por su habilidad para sobrevivir a diversas condiciones climáticas extremas, con efectos mínimos sobre sus poblaciones. La ecología alimenticia y los patrones diarios de actividad de dos razas se estudiaron desde junio 1981 hasta septiembre 1983. Una raza tiene caparazón en forma de cúpula y vive en la Isla Santa Cruz. La otra tiene caparazón en forma de montura y se encuentra en Pinzón. El inicio de El Niño originó una migración masiva de las tortugas desde las partes altas a las áreas bajas en la Isla Santa Cruz. Sus patrones diarios de actividad no cambiaron sustancialmente, aunque con la abundancia de vegetación resultante de El Niño las tortugas se alimentaron durante un gran porcentaje de las horas del día. Los patrones de colección

y de flujo de las aguas de inundación de El Niño parece que fueron el factor determinante para delimitar los tipos de hábitat en las zonas de Transición/Scalesia en los alrededores de la Caseta y de El Chato en Santa Cruz. Otros efectos importantes de El Niño sobre la vegetación tanto de Santa Cruz como de Pinzón fueron un aumento general en el número de especies, un gran incremento de plantas trepadoras y la destrucción de árboles de *Opuntia*. Los estudios en Pinzón mostraron resultados semejantes a los de Santa Cruz, incluyendo un incremento en el tiempo que las tortugas dedicaron a la alimentación y en una dieta más variada como consecuencia del mayor número de especies vegetales. No hubo cambios en la distribución de tortugas en Pinzón durante El Niño. Con frecuencia se vio a los pinzones sacando garrapatas de las tortugas durante la estación seca anterior a El Niño, pero en raras ocasiones durante la estación húmeda. Los grandes ríos de El Niño 1982-83 sugieren una forma cómo las tortugas se dispersaron originalmente entre las islas, después de la llegada de las primeras tortugas del continente. Su longevidad, la baja actividad metabólica y la baja tasa de mortalidad de los adultos, han permitido a las tortugas "esperar" durante períodos de condiciones climáticas extremas, los que pueden causar situaciones de "cuello de botella" para otras especies de la fauna de las Islas Galápagos.

Introduction

Of the Galápagos fauna, giant tortoises (*Geochelone elephantopus*), the major large herbivore native to the islands, were perhaps the least affected either positively or negatively by the 1982–83 El Niño event. Their ability to survive both drought and periods of exceptionally heavy rainfall, such as the 1982–83 El Niño, with negligible effect on population size, makes them unique among the fauna of the islands. This survival ability has been noted for both domed and saddle-backed tortoises, the two morphological extremes among the races. A race of domed tortoises (*G. e. porteri*) was studied on Santa Cruz, a large, wetter, and more elevated island with a great diversity of vegetation zones, while a race of saddle-backed tortoises (*G. e. ephippium*) was studied on Pinzón, a smaller, drier island with much less diversity of vegetation zones. Description of the vegetation of these islands is found in Hamann (1981), van der Werff (1978), and Wiggins and Porter (1971).

Feeding ecology and daily activity patterns of giant tortoises were studied from June 1981 to September 1983. Major study areas were established in the Tortoise Reserve on the southwestern slopes of Santa Cruz (Fig. 1). The reserve (166 km²) includes a variety of vegetation zones along the gradient from the sea to an elevation of approximately 200 m (Reeder and Riechert 1975). The region encompasses tortoise nesting sites and feeding and resting areas for all seasons and supports a tortoise population of 3,000 to 4,000 animals (F. Cepeda, pers. comm., 1981), of which more than 2,000 have been marked by SPNG personnel.

Study areas were established in June 1981 at the Caseta and El Chato (Fig. 1), both at the edge of the upper Transition Zone and the lowermost *Scalesia*

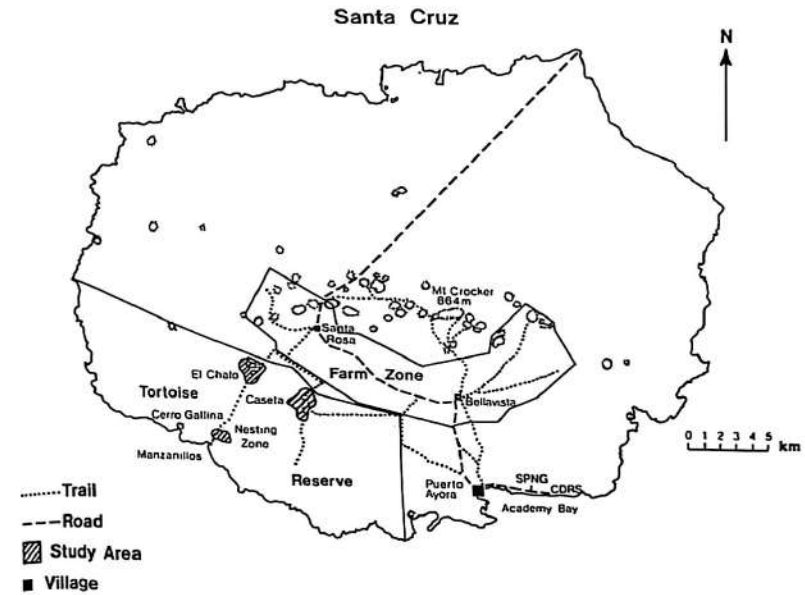


Figure 1. Santa Cruz Island. Location of study areas at the Caseta, El Chato, and the nesting zone above Manzanillos. (After map prepared by CDRS, 1972).

Zone at elevations between 150 and 200 m (Wiggins and Porter 1971). Some tortoises remain in these areas throughout the year, although during the latter part of the hot season (January–May) females migrate to the Arid Zone to nest (Rodhouse et al., 1975). During the period from June 1981 to December 1982, both sexes of tortoises were found using these study areas in all months, although there was a reduction in percentage of females during the nesting season.

During El Niño, an additional study area was established in the Tortoise Reserve, at the nesting zone (elevation 50–80 m) located inland from Manzanillos (Fig. 1), in an area with vegetational char-

acteristics common to the Arid Zone and the Transition Zone.

Pinzón was first visited in April/May 1982, at the end of a hot season with little precipitation. This population of tortoises was studied intensively for a 3-week period, then again in December 1982, and June 1983.

In addition to the ecology of tortoises, emphasis was placed on characteristics of the vegetation, including both monthly and seasonal changes in abundance and phenology, and descriptions of habitat types encountered within each of the study areas.

The two-year research program provided the unique opportunity to observe and study tortoises and their environment through a hot season in 1982, with little rainfall, followed by the exceptionally strong 1982-83 El Niño event (Table 1).

Methods

Observations of tortoises and measurements of the vegetation were the principle components of this research. Both instantaneous and continuous observations of tortoises were done. During periods of instantaneous observation, all tortoises seen throughout the study area were noted, as well as time, temperature, weather, activity, food items if eating, and habitat type. For constant monitoring of individuals, a single tortoise was followed for a 2-day period. All activity was recorded as for instantaneous observations.

To determine food availability, vegetation transects (200 m² quadrats per study area) were completed every two months from June 1981 to June 1983, at the Caseta and El Chato, in April and July 1983, at the

nesting zone on Santa Cruz, and on the first two trips to Pinzón. Percent cover by species was estimated for those plants below the maximum foraging height of tortoises. The transects were laid 25 m on either side of the main trail in each study area, in the region of greatest tortoise activity. Quadrats were placed 10 m apart as were adjacent transects.

Results and Discussion

Santa Cruz Tortoises

The most immediate effect of El Niño on tortoises on Santa Cruz was a change in distribution. Beginning in December 1982, with the first major storms, tortoises of both sexes began a mass migration to lower elevations. Whereas in the previous 1½ years, the same individuals were seen for periods of weeks to months in each of the upland study areas, during December 1982 and January 1983, few tortoises were seen remaining in those areas for a period greater than a few days (Figs. 2 & 3). Searches made at those study areas at intervals throughout El Niño revealed a continuing low density of tortoises (Tables 2 & 3). During the previous year and a half, observations of traveling tortoises, most often recorded during feeding bouts or while moving to or from a resting area or pond, showed no directional component. During both December 1982 and January 1983, however, greater than 50% of the observations were of tortoises moving steadily south, toward lower elevations (64% and 56%, respectively for the two months). Tortoises were seen entering the study areas from farmlands above and later exiting at the lower edge of the area. For example, a large male, No. 229, was located at the Caseta (the northern entrance of the study area) at 15:00 on 20 December and was seen leaving the southern end of

Table 1. Rainfall data for the Caseta and the Charles Darwin Research Station (CDRS), Santa Cruz, from 1 June 1981 to 31 August 1983, and the corresponding numbers of plant species recorded in vegetation transects (VTs) at the Caseta and El Chato. Time periods given are dependent upon dates when precipitation readings were made at the Caseta. From 8 December 1982 to 8 April 1983, data in the Caseta column were measured at the Devine's farm, north of the Caseta (S. Devine, pers. comm.). NR = not recorded.

Year	Time Period	Precipitation (mm)		No. of Plant Species in VTs	
		CDRS	Caseta	Caseta	El Chato
1981	June 1-30	2.1	NR	46	—
	July 1-17	3.3	NR	49	51
	July 18-26	1.2	11.4		
	July 27-Aug. 4	0.0	NR	48	51
	Aug. 5-17	1.2	26.9		
	Aug. 18-26	0.0	NR		
	Aug. 27-30	0.0	0.0		
	Aug. 31-Sept. 28	10.2	68.8	53	54
	Sept. 29-Oct. 18	6.6	31.2	63	56
	Oct. 19-23	0.5	NR		
	Oct. 24-31	0.8	14.5		
	Nov. 1-30	3.2	12.7	47	55
	Dec. 1-28	36.6	67.3		
1982	Dec. 29-Jan. 30	14.1	70.4	56	54
	Jan. 31-Feb. 28	22.2	68.3		
	Mar. 1-30	11.5	28.4	43	49
	Mar. 31-Apr. 18	1.9	3.0		
	Apr. 19-May 31	13.4	5.6	39	42
	June 1-30	4.2	31.8		
	July 1-31	9.0	96.0	57	55
	Aug. 1-31	5.7	75.2		

Table 1. continued.

Year	Time Period	Precipitation (mm)		No. of Plant Species in VTs	
		CDRS	Caseta	Caseta	El Chato
1983	Sept. 1-30	6.1	57.2	70	64
	Oct. 1-4	3.7	NR		
	Oct. 5-27	2.3	34.8		
	Oct. 28-Nov. 26	13.9	266.4	70	62
	Nov. 27-Dec. 7	72.0	NR		
	Dec. 8-Jan. 2	497.6	750.3		
	Jan. 3-31	278.7	511.8	70	67
	Feb. 1-28	91.9	417.8		
	Mar. 1-22	130.9	338.1	70	62
	Mar. 23-Apr. 8	286.0	325.6		
	Apr. 9-30	315.4	NR		
	May 1-31	660.2	NR	72	62
	June 1-30	637.5	NR		
	July 1-12	257.2	NR		
	July 13-31	21.0	NR		
	Aug. 1-31	5.4	NR		

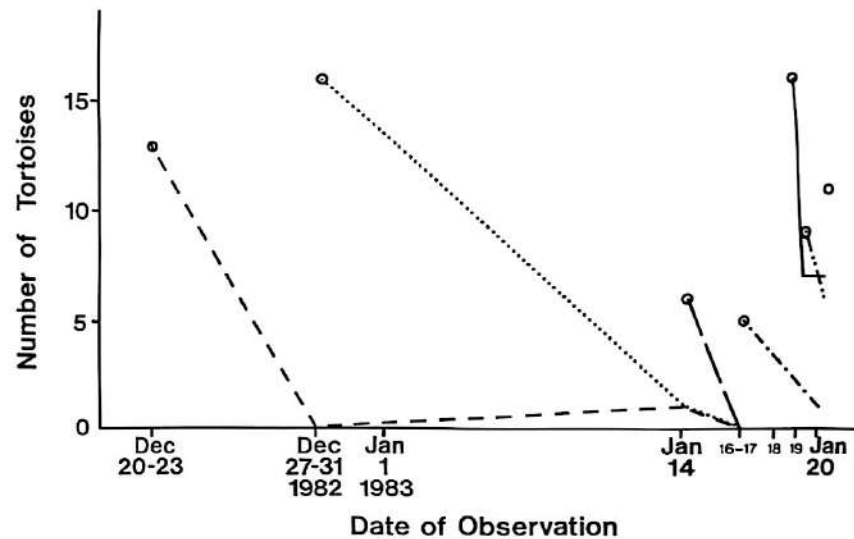


Figure 2. Marked tortoises observed at the Caseta study area during the peak of migration from the highlands to the lowlands at the onset of El Niño. Of the 31 marked tortoises seen in the area in November 1982, only one was seen in December (observations beginning 20 December). Circles indicate the total number of marked tortoises seen during each observation period. Lines indicate the number of tortoises seen on a given date of observation and relocated in the area on succeeding days.

the study area at 14:30 the following day, a distance traveled of approximately 1.5 km. Although the peak of migration was in December and January, tortoises continued to move to lower elevations for several months.

What caused this major migration immediately at the onset of El Niño rains? It is possible that the rainfall of December 16-17, with precipitation measured at greater than 200 mm at the Devine's farm, immediately north of the Caseta (S. Devine, pers. comm.), causing the first major flooding, triggered the movement down. Characteristics of the Transition/*Scalesia* Zone during El Niño that may have been unfavorable to tortoises included periodic large

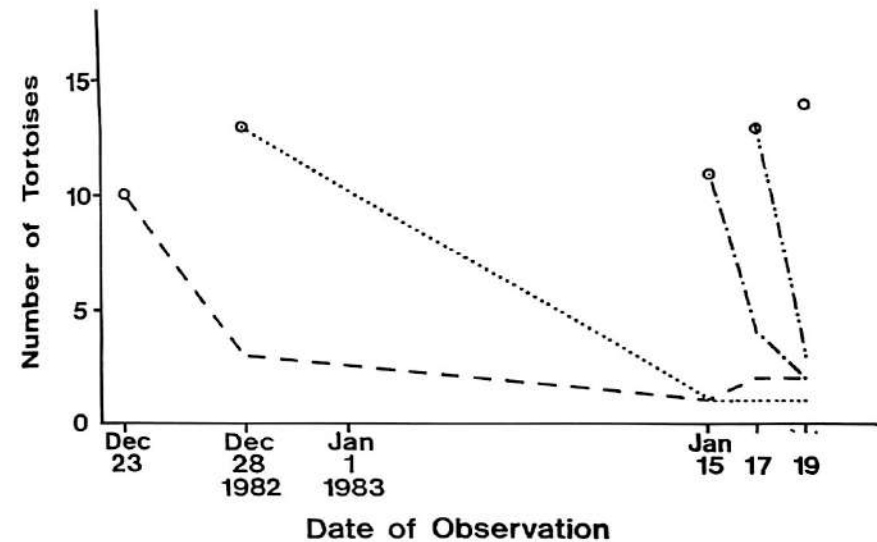


Figure 3. Marked tortoises observed at the El Chato study area during the peak of migration from the highlands to the lowlands at the onset of El Niño. Of the 45 marked tortoises seen in the area in November 1982, only two were seen in December (observations beginning 23 December). Circles indicate the total number of marked tortoises seen during each observation period. Lines indicate the number of tortoises seen on a given date of observation and relocated in the area on succeeding days.

rivers, often greater than 40 m wide and 50 cm deep (Fig. 4), which swept through most of the open areas; an incredibly high density of vegetation which made movement, even by tortoises, difficult; semi-permanent ponds, normally used by tortoises, filling to depths much greater than tortoise height; and mud throughout the area making travel difficult. The nesting zones, on the other hand, had open areas which were not inundated periodically by rivers, a lower density of vegetation providing better access to feeding and resting areas, periodic ponds which were not of great depth and which drained rapidly, and much less soil development, making the majority of travel over rock, which was much more easily traversed than mud.

As noted in Tables 2 and 3, some tortoises remained at El Chato throughout El Niño, whereas the Caseta area was completely abandoned. Possible reasons for this difference include differences in vegetation and water flow characteristics associated with the terrain. At the Caseta, periodic heavy rainfalls causing flooding created rivers which encompassed nearly all of the open areas as well as the trails most often used by tortoises. Adjacent areas were very densely vegetated. At El Chato, there were several grassland areas which were not periodically covered with flood waters. Each of the four tortoises, all large males, remaining at El Chato through most of El Niño (Nos. 193, 1/10 flat, 302, and 139), had a home range which they maintained in fairly open condition by using the same paths and

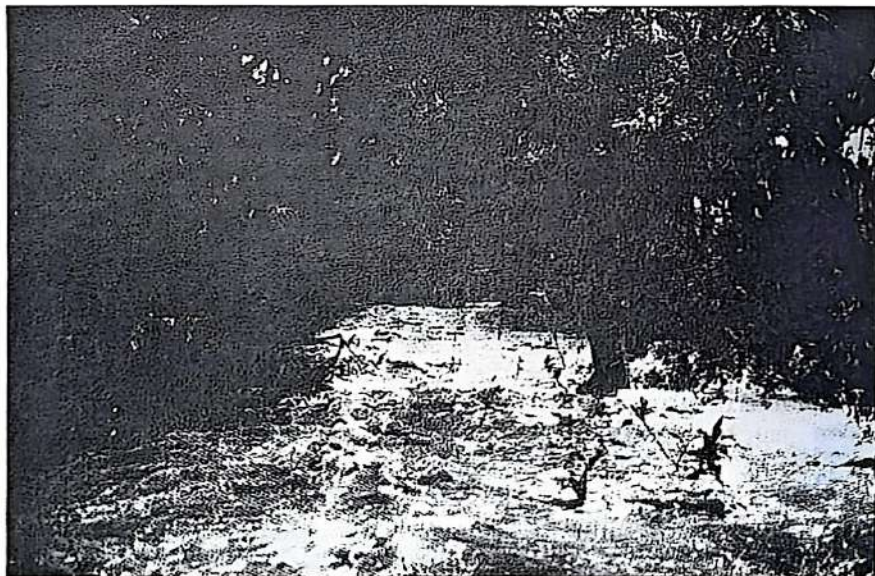


Figure 4. River running through a *Hippomane* woodland (HAW) at the Caseta during a moderate flood period in February 1983.

Table 2. Tortoises observed at the Caseta from December 1982 to September 1983. Animals seen more than once are listed by their identification number. The number of additional tortoises observed during each time period that were not subsequently seen is indicated in parentheses below the identification numbers.

Dates of Observation							
Dec. 20-31	Jan. 14-20	Feb. 5-7	Mar. 21	Apr. 28	May 18	May 27	Sept. 11
19	19						
213	213						
474		474					
1273	1273						
2046	2046						
	192	192					
(24)	(24)	(3)	(4)	(0)	(0)	(0)	(7)

Table 3. Tortoises observed at El Chato from December 1982 to August 1983. Animals seen more than once are listed by their identification number. The number of additional tortoises observed during each time period that were not subsequently seen is indicated in parentheses below the identification numbers.

Dates of Observation							
Dec. 20-31	Jan. 15-19	Feb. 10-11	Apr. 1-2	Apr. 28	May 17	May 24	Aug. 13
26	26						
193	193	193	193	193	193	193	193
32-70	32-70						
	1/10 F	1/10 F	1/10 F	1/10 F	1/10 F	1/10 F	1/10 F
		302	302	302	302	302	302
			139	139	139	139	139
				440	440		
					20	20	
					504	504	504
(19)	(25)	(3)	(1)	(2)	(1)	(0)	(3)

feeding areas repeatedly. Outside of those areas the vegetation was very high and dense, similar to that found at the Caseta.

The rainy period of El Niño ended mid-July 1983 (Table 1). The upland ponds began to dry and all rivers were completely dry by mid-August. By the end of November, there was no standing water, though some areas were still muddy. Tortoises began returning to both the Caseta and El Chato, as well as entering the farmlands above, by the end of August and beginning of September. The area was not visited by researchers between 11 September and 30 November. Thirty tortoises were encountered on a hike from Santa Rosa to the pond at the Caseta on 30 November. Eighteen tortoises were seen during a day hike, Santa Rosa to El Chato, 17 December. These observations are equivalent to the numbers of tortoises usually seen by tourists in non-Niño years.

Daily activity patterns of tortoises did not change relative to normal seasonal changes. Food habits changed in accordance with species changes between the Transition/*Scalesia* Zone and the Arid-Transition Zone. However, with the abundance of food in the nesting zone, feeding behavior remained much the same. Cactus (*Opuntia echios*), often considered a preferred food item of tortoises only in the dry season (Thornton 1971, Dawson 1966), remained a highly preferred food item during El Niño, although it made up a low percentage of the diet due to the abundance of other foods. In both wet and dry seasons, tortoises tended to feed on *Opuntia* whenever encountered during daily travels (Fig. 5).

Effects of El Niño on hatching and nesting are uncertain. Hatchlings, with a curved carapace length (ccl) of 6-9 cm, are difficult to detect (MacFarland et al., 1974), and with the increase in vegetation associated with El Niño, even young tortoises (ccl up to 25 cm) were difficult to find. One hatchling

and three young tortoises were located in the nesting zone, and no tortoises with a ccl between 25 and 75 cm were found. If hatchlings were able to emerge from the nest, conditions were favorable as the food supply was much more abundant than most years. However, some nests were flooded by rivers or ponds. Therefore, the ultimate effect of El Niño on hatchling emergence and survival is difficult to estimate.

Females attempted to nest in July 1983, when the ground was still wet. These nests were abandoned prior to completion. On one occasion, a broken egg was found adjacent to an unfinished nest hole. The nesting season of tortoises throughout the islands coincides with garúa season (June to December) (MacFarland et al., 1974). By mid-August, the soil at



Figure 5. Old female tortoise feeding on a fallen *Opuntia echios* trunk in the nesting zone, Santa Cruz, July 1983.

the Charles Darwin Research Station, located in the Arid Zone, had dried sufficiently for the captive breeding population of tortoises from Española to nest successfully. It is probable that the soil in the natural nesting zones of Santa Cruz was also sufficiently dry by that time to allow successful nesting. Therefore, El Niño may have postponed the onset of the nesting season without any major effect on the ultimate outcome.

Santa Cruz Vegetation - Caseta/El Chato

The 1982-83 El Niño event was a key factor in understanding the cause of the overall pattern of vegetation communities in the Transition/*Scalesia* Zone. By the end of 1981, habitat types had been defined for the Caseta/El Chato study areas, determined mainly by dominant plant species. The more important include:

- HAW: *Hippomane mancinella* woodland; broad canopy with single tree species; open understory.
- PZW: *Psidium galapageium* / *Zanthoxylum fagara* woodland; dense woodland with a greater density of shrubs and forbs in the understory; other tree species include *Croton scouleri*, *Pisonia floribunda*, and *Piscidia carthagenensis*; dominant shrubs are *Psychotria rufipes* and *Tournefortia rufo-sericea*.
- CMT: *Clerodendrum molle* thicket; dense thicket with few other species; often found around dry water holes.
- UG: Underutilized grassland; dominated by *Paspalum conjugatum*; open areas with few to no trees; generally grasses not cropped to ground level; important forb species include *Blechnum brownei* and *Desmodium canum*.

- GL: Grazing lawn; dominated by *Stenotaphrum secundatum*; open areas of heavy grazing; often several forb species included.
- OF: Open forb; open areas with few to no trees, dominated by forbs; often surrounded by PZW; important species include *Desmodium canum* and *Cassia occidentalis* in drier areas, and *Ageratum conyzoides* in wetter areas; *Cassia picta* and *Rhynchospora nervosa* often abundant in both wet and dry areas.
- SCPT: *Scleria pterota*; robust sedge which grows clumped; most often with no other species.
- DWH/WH: Dry water hole/water hole; generally open areas, ranging in size from small holes with a 2 m diameter to large areas up to 40 x 60 m; plant species vary depending on locale; ponds fill periodically with sufficient rainfall.

The two woodland types (HAW and PZW) dominate the area. However, delineating between the two was often difficult due to spread of one type into the other, most often the occurrence of *Zanthoxylum* and *Psidium* in HAWs. Once El Niño began, the delineation of habitat types became more clear due to the pattern of water collection and movement associated with characteristics of the terrain. The outer limits of HAWs clearly coincided with low regions where water collected, and flooded regions around the edges of ponds and along rivers (e.g., where the largest flood rivers were 40 m across, the HAW encompassed the entire area, ending at the edge of the flood waters) (Fig. 4). In these flood areas, *Zanthoxylum* and *Psidium* trees, that had managed to invade the HAW during years of low to moderate rainfall, died as a result of flooding. Other species which thrived when located in high spots but did poorly and often died in frequently flooded areas included *Croton*,

Psychotria, and *Scalesia*.

Hippomane mancinella is a unique species in that its more common distribution is along the coast in littoral scrub (Wiggins and Porter 1971), however, it is a dominant type in certain areas of the Transition/*Scalesia* Zone. Hamann (1981) described its curious distribution in the Galápagos in littoral scrub, dry season deciduous steppe such as that in the lowland nesting zone, and in the upland evergreen forest around the Caseta and El Chato. Hamann suggested that *Hippomane* requires or tolerates a high content of water-saturation in the soil. The strong correlation between HAWs and river/pond distributions in the Transition/*Scalesia* Zone support this idea. Tortoises may be an important dispersal agent for *Hippomane* (Rodhouse et al., 1975). The fruit of *Hippomane* is a very highly preferred food item of tortoises. Given the long rate of passage through the gut of tortoises, ranging from 7 to 21 days (Rick and Bowman 1961, and this study), it is possible that tortoises were the original dispersal agent for *Hippomane*, bringing it from the coast to higher elevations. Major historical tortoise trails between nesting zones and higher elevations follow the major river systems delineated during the past El Niño, and it is along these drainages that HAWs are most abundant.

Psidium/Zanthoxylum woodlands were predominantly on raised areas with no water collection. Small sections of these woodlands where water concentrated in run-off were usually inhabited by *Pisonia* and *Piscidia*, which did not occur often in the rest of the PZW.

Clerodendrum thickets occupied areas of gently sloping terrain around the outer edges of ponds, and in many river bed areas.

Underutilized grasslands were found in open

areas that did not flood. At edges of these grasslands, where low spots occurred and water collected, the *Paspalum* regions ended and the common habitat type was SCPT. Similar low spots in woodlands were often dominated by *Scleria* also.

Grazing lawns were the one habitat type maintained by tortoise grazing. They were generally drier than *Paspalum* grasslands. During the extremely dry period in 1982, many forbs increased in dominance in these areas. By the end of El Niño, with the complete lack of tortoise grazing and the increase in moisture, this habitat type had disappeared, and the areas were dominated by forbs.

Sedges became much more abundant with the increase in wet areas, particularly *Eleocharis* spp., which is most often found on the edges of small water holes, and *Cyperus brevifolia*, which became extremely abundant in the wetter portions of UGs and GLs. *Blechnum brownei* also became much more abundant in wetter *Paspalum* grasslands.

Open forb areas remained much the same during El Niño, although most of the species, normally less than 1 m high, grew to between 1.5–2.5 m. Many areas were dominated by *Cassia picta* and *Ageratum conyzoides*. *Ludwigia erecta* also became abundant in these areas as well as in old GLs. It was the only species of great abundance during El Niño which had not been seen in the study area prior to November 1982.

During the study, many areas were called dry water holes due to appearance and species composition. El Niño provided confirmation for all of these although some were actually river beds. Many species normally abundant in DWHs and adjacent areas were flooded at the onset of heavy rains and were subsequently absent or greatly reduced throughout El Niño.

Two major types of ponds developed: Those which were part of a river system and were periodically flushed; and those which were isolated from river systems and were not flushed. In addition, there were small pockets of water in the soil throughout the woodlands. These were usually filled with *Chara* sp. The large pond at the Caseta is a good example of the first type of pond. Vegetation transects were measured on this pond every two months, beginning November 1981, when it was completely dry. Once filled in November 1982, it was dominated by *Enydra maritima*, which had first appeared as the pond dried in 1981, and by *Naja guadalupense*. By May 1983, the pond had been flushed so often during floods that the *Naja* was nearly gone and much of the *Enydra* had been washed out of the pond. Much of this vegetation could be found stuck to tree trunks further along the river's path. By this time, much of the upper half of the pond had been filled in with silt washed down from higher elevations. Much soil in the highlands, particularly from the farmlands, is apparently lost to the lowlands during major El Niño events.

Two large ponds at El Chato are representative of the second type of pond mentioned. The smaller of these was also monitored using vegetation transects, beginning November 1981 to May 1983. These ponds first filled in late November 1982, and by January 1983, were covered by *Azolla microphylla* and *Naja guadalupense*. As the season progressed, the layer of *Azolla* continued to increase up to more than 10 cm deep, during which time the *Naja*, deprived of light, gradually died out. The larger of these ponds filled to a depth of greater than 2 m, and spread out into the adjacent CMTs and HAWs, maintaining a depth of greater than 1 m on the tree trunks of *Hippomane* for several months (Fig. 6).

The number of species encountered in vegetation transects at both the Caseta and El Chato was greater throughout El Niño than in previous months (Table 1).

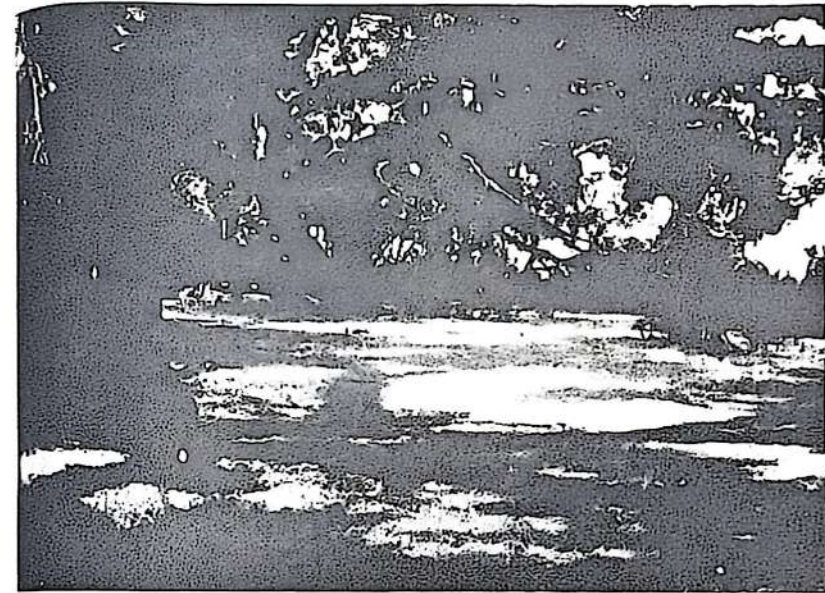


Figure 6. Pond waters, covered by *Azolla microphylla*, flooding a *Hippomane* woodland (HAW) at El Chato during the 1982-83 El Niño. Depth of water on the tree trunks is approximately 1 m. (May 1983).

Flowering by most species was prolific during the first months of El Niño, with a gradual decline through the season, associated with a tremendous increase in leaf and stem production. Neither *Psidium* nor *Hippomane* produced as much fruit as in other years, and most of what did fall to the ground was soon washed away by flood waters and/or rotted within a few days.

Vines became dominant and covered much of the vegetation. At the Caseta and El Chato, the most abundant vines were *Stictocardia tallifolia* and *Nomordica charantia*. *Stictocardia* was reported by Wiggins and Porter (1971) to be possibly introduced. Its widespread occurrence in the native woodland,

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while other introduced species are generally concentrated at the edges and along trails, suggests that it is in fact indigenous. If introduced, it is the only introduced species which played a dominant role in the vegetation. *Stictocardia* covered entire trees (most often *Zanthoxylum*) and large sections of CMTs. In some cases, the weight of the vines along with the increased leaf growth of the tree caused the tree stem to break.

In general, introduced plant species have not been able to successfully invade the native vegetation of the Transition/*Scalesia* Zone as they have the *Miconia* Zone at higher elevations (Kastdalen 1982). Many introduced species are found close to the opening at the Caseta and along the initial kilometer of trail leading into both study areas, but have been unsuccessful in dispersing far from the trail. Perhaps the most successful are various species of *Citrus*, including oranges, lemons, and grapefruits. Unfortunately, tortoises feed on the fruit of these species when available, and will continue to assist in seed dispersal throughout the area. *Sida rhombifolia* (locally called "escoba") is the only other introduced species which made obvious inroads into the area during El Niño. This species is indigenous to the islands (abundant on San Cristóbal and Isabela) but was apparently introduced to Santa Cruz from San Cristóbal (Kastdalen, note on herbarium specimen, CDRS, collector - D.W. Snow, 9/V/63). The distribution of *Sida rhombifolia* on Santa Cruz exhibits that of an introduced species, being found in town, along roadsides and trails, but not widespread within the native vegetation.

The major rainfall of El Niño ended in mid-July 1983, and by August the vegetation was drying rapidly. Some species, which had declined or disappeared when the ponds filled, began to reappear along the edges of the drying ponds. Many species that had appeared at the onset of El Niño, including *Ludwigia erecta*,

were dying throughout the area. As tortoises moved back into the Caseta/El Chato region, they quickly opened areas by smashing down the vegetation as they traveled. Both traveling tortoises and vegetation dying along river banks helped to knock soil back into some of the smaller gullies cut by the flooding rivers. My impression after visiting the area in August and again in September was that the combined effect of a dry period, the return of the tortoises, and the dying vegetation would accelerate the rate of return to "normal non-Niño conditions."

Santa Cruz Vegetation - Nesting Zone

The nesting zone was predominantly a *Pisonia floribunda*/*Piscidia carthagenensis* woodland, with some *Erythrina velutina*, *Zanthoxylum tagara*, *Psidium galapageium*, *Bursera graveolens*, as well as *Opuntia echios*. There were several shrub species but none were exceptionally abundant. Several forb species were abundant but grasses and sedges were scarce. The number of species encountered in vegetation transects (49 and 50) was intermediate between the upland areas of Santa Cruz and the valley of Pinzón. As in the upland areas, flowering was most common early in the El Niño season.

As throughout much of the archipelago, a vine, in this case *Ipomoea triloba*, was by far the most abundant species from February through April 1983. Like *Stictocardia* in the Transition/*Scalesia* Zone, *Ipomoea* covered everything, including rocks, open soil, shrubs, forbs, tree trunks, and entire cactus plants (Fig. 7). By July, the *Ipomoea* was nearly gone, apparently a result of the extremely severe flooding in May and June.

Several plant species previously more common in the Caseta/El Chato region began appearing in the nesting zone as El Niño progressed predominantly near trails. Transportation of seeds and by the

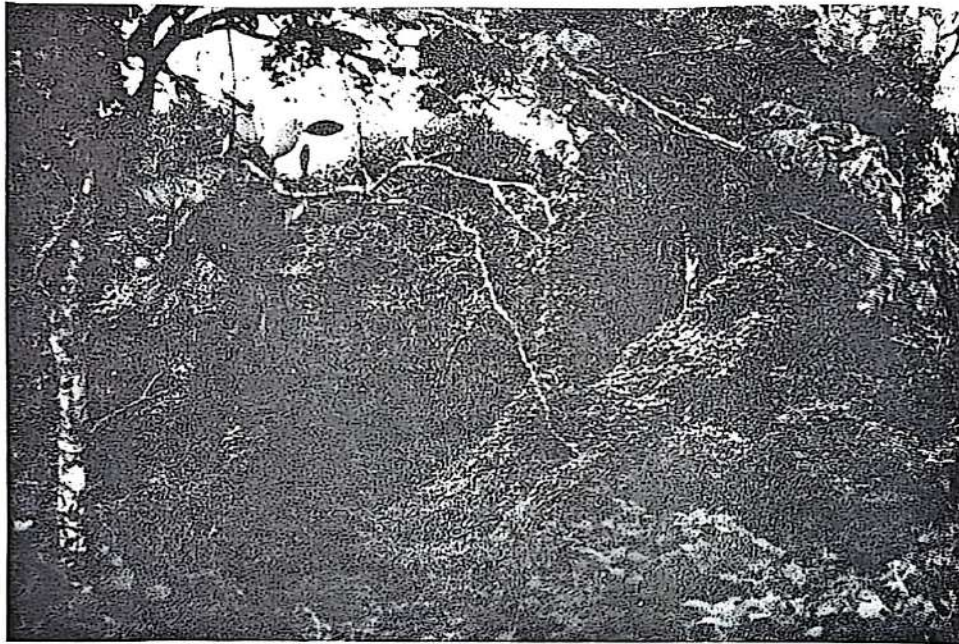


Figure 7. *Ipomoea triloba* covering the majority of the vegetation in a tortoise nesting area on Santa Cruz (Arid/Transition Zone) during the 1982-83 El Niño. (April 1983).

either by tortoises or by horses used by residents of Santa Rosa on their travels to and from the coast. These included 11 forbs, 1 grass, and 1 sedge.

Several trees were found fallen or broken. These were primarily *Pisonia* and *Erythrina*. As indicated by Hamann (this volume), *Opuntias* were severely damaged by El Niño, due to a combination of root rot, excess moisture in their pads making them top-heavy, and reduction in light due to the surrounding vegetation and the many vines covering them.

Pinzón Tortoises and Vegetation

Vegetation in the study area on Pinzón, located in the valley or South Crater (Fig. 8), is predominantly xerophytic (Hamann 1981). Dominant species

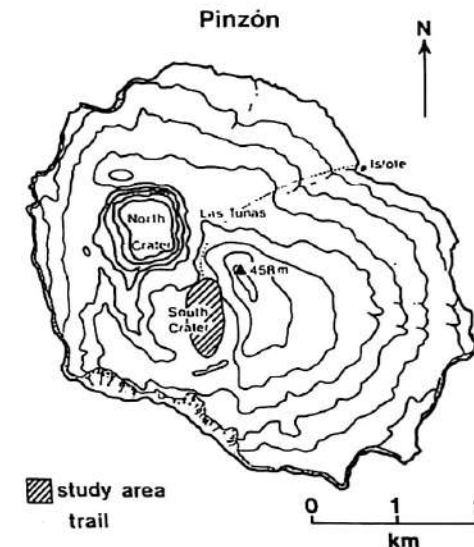


Figure 8. Pinzón. Study area located in the central valley of Pinzón (South Crater). (After map prepared by CDRS, 1972).

include *Prosopis juliflora*, *Alternanthera filifolia*, *Maytenus octogona*, *Croton scouleri*, and *Opuntia galapageia*. Precipitation in the valley was similar to that recorded at CDRS during comparable periods.

The December trip to Pinzón coincided with the onset of El Niño and tortoises were observed throughout the period of initial flooding. Upon arrival in the valley, 1 December, there was no standing water except in a few small rock pockets. There had already been adequate rainfall for the vegetation to commence growth and many species were in flower. By 10 December, there was standing water throughout the valley. By 14 December, the first river, approximately 1.5 m wide, was flowing out of the valley to the North Crater. An interesting phenomenon, observed in the valley, predominantly in dry water holes, and

on the outer rim in the *Opuntia* area known as Las Tunas, was the occurrence of pitfalls in the soil resulting from an underground river system which undermined the soil surface. Some of the pits were greater than 1 m deep. During the early storms, most of the water left the valley through this underground system and several new pits caved in. It was not until the big storm of December 16-17 (132.6 mm precipitation in the valley) that the underground system backed up, surface ponds filled, and large rivers flowed.

Tortoises devoted more time to feeding and less to resting during the onset of El Niño than they had in the hot, dry period of April/May 1982. Data from ten 2-day observations of individuals indicated that in the dry period tortoises spent 77.3% and 9.6% of daylight hours resting and feeding, respectively. In December 1982, similar data from 9 individuals indicated that 61.7% of the daylight hours was spent resting, while 27.3% was spent feeding. The rest of the time was occupied in traveling, interactions with other tortoises, and maintenance activities.

The number of plant species in vegetation transects increased during May to December from 28 to 40, providing a much greater variety of food items for tortoises. Along with the increase in number of species was a corresponding increase in the number of individuals, as well as in productivity. Tortoises shifted from eating primarily *Opuntia* (49% of the diet), and *Portulaca* (10%), along with 11 other species in May, to eating a more varied diet including the three most often eaten species, *Portulaca* (27%), *Commelina diffusa* (19%), and *Lantana peduncularis* (11%), along with 21 other species in December. As indicated for tortoises on Santa Cruz, although *Opuntia* made up less of the total diet in the wet period, it was still highly preferred.

As in other areas throughout the islands, vines,

here *Ipomoea triloba* and some *Anredera ramosa*, had spread over much of the area and the vegetation. In vegetation transects *Ipomoea* had a frequency of 71%.

The only species that had decreased significantly by December were *Maytenus octogona*, *Castela galapageia*, and the hanging green lichen. All other species had remained the same or increased in abundance and percent cover. Rocky areas that had been dominated by *Maytenus* were now covered with *Commelina diffusa*.



Figure 9. Saddle-backed tortoise in the central valley of Pinzón at the end of the 1982-83 El Niño. Vegetation covered nearly 100% of the valley floor. (June 1983).

By June 1983, there was extremely dense plant growth both inside and outside the craters. The valley was almost completely covered with vegetation except in open pond areas (Fig. 9). Although vegetation transects were not done at this time, *Croton* appeared to have the largest increase in abundance. *Ipomoea* also was still extremely abundant. Following six months of severe flooding, many species were doing poorly, including *Alternanthera*, *Commelina*, *Castela*, *Maytenus*, and *Portulaca*. The latter had been abundant in December in the dry water holes prior to flooding. As at the Caseta, *Croton* was dying in flooded areas, as was *Prosopis*. Many *Opuntia* had fallen. *Panicum geminatum*, well adapted to wet areas, had increased greatly, as had *Cyperus elegans*. The Galápagos tomato, *Lycopersicon cheesmanii*, and an unknown annual, neither of which had been seen on previous visits, were extremely abundant around the big central pond. By the end of El Niño, the valley was a series of inter-connected ponds and the North Crater was filled with water (Figs. 10 & 11).

Tortoises did not show any change in distribution on Pinzón resulting from El Niño. Twenty tortoises were reencountered in June 1983, and all had remained in the general area in which they had been found during the two previous trips.

Tortoises and Finches

A comparison of the cleaning symbiosis involving tortoises and small ground finches (*Geospiza fuliginosa*), as described by MacFarland and Reeder (1974) was made between the dry, hot period in April and May, and the onset of El Niño in December 1982. During ten 2-day watches of tortoises during April and May, male ground finches were observed removing ticks from tortoises 32 times. MacFarland and Reeder (1974) suggested that the absence of this symbiotic behavior during a wet season on Alcedo, when ticks

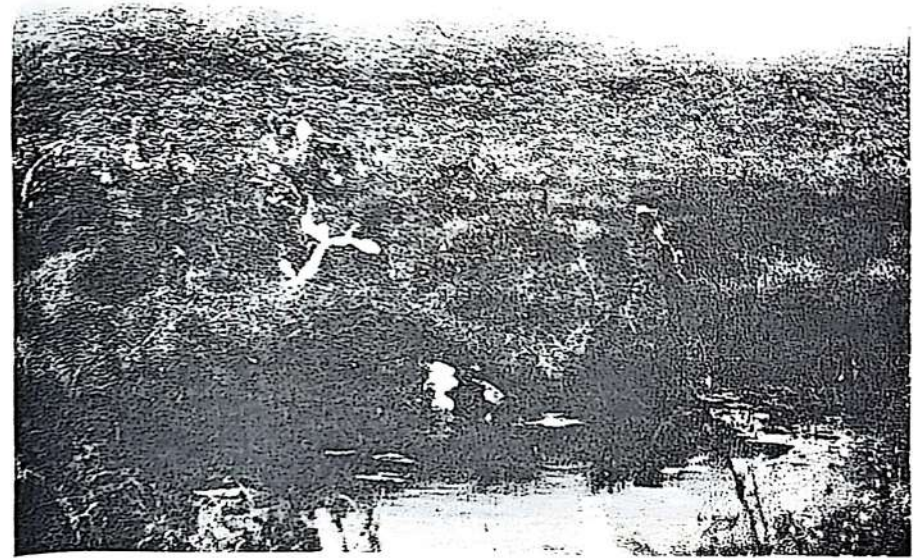


Figure 10. A series of ponds filled the bottom of the central valley of Pinzón by the end of El Niño. The extremely high abundance of vegetation and the decimation of *Opuntia* are evident.

were abundant, was probably due to the inability of the finches to locate ticks on mud-covered tortoises. Our December trip to Pinzón began prior to the occurrence of standing water, allowing an examination of this behavior during a wet season when the tortoises were not yet covered with mud. During the nine 2-day watches in December, spanning the period before and after tortoises began wallowing in mud holes, only two cleaning attempts with no successful tick removal, and one successful cleaning period which lasted for less than 1 minute were observed. Ticks were abundant during this time. On Pinta, food availability for *Geospiza fuliginosa*, in terms of seeds, was shown to decline dramatically during the dry season, and the ground finches were found to



Figure 11. Water filled the North Crater of Pinzon by the end of El Nino. (June 1983).

select food for which handling efficiency was greatest and which occurred in patches of highest profitability (Schluter 1982). This suggests that during the dry season on Pinzón, as well as on other islands where this behavior occurs, the tick provides an important portion of the finch diet (MacFarland and Reeder 1974), perhaps protein or water, which is absent or more difficult to obtain from other sources; whereas, in the wet season, that same portion of the diet is more efficiently obtained elsewhere, regardless of similar cleaning efficiencies for ticks on tortoises between the dry and wet seasons.

El Niño and Tortoise Dispersal within the Archipelago

A behavioral characteristic observed in tortoises on Pinzón during the onset of El Niño, and later at the Caseta, consisted of an alarm reaction to sudden extremely heavy rainfall at dusk. On 16 December, the major period of heavy rainfall began at approximately 17:00 hours. During the next hour, I was making observations of tortoises. Normally the presence of an observer does not disturb a tortoise once it has bedded down. That evening, upon my approach, several tortoises got very agitated and began shifting around in their mud forms. Two tortoises began to immediately leave their form. As the rain suddenly increased in intensity, a smaller tortoise, who was bedded down in a shallow pond, immediately left the pond and moved into the woods, onto higher ground. A situation similar to this occurred the next week at the Caseta. Two tortoises had bedded down in small water holes in mid-afternoon. At 18:00 hours, it began to pour heavily. The smaller of the two tortoises immediately left its water hole and moved several meters higher into the woods. The other tortoise, a large old male, shifted to the far end of its water hole, moving out onto the edge until his plastron was settled onto firm ground.

These incidents, of tortoises of all sizes reacting negatively to sudden heavy rains in the evening, suggest the evolutionary importance of moving away from potential flood areas. This behavior would have been adaptive to the ancestral stock living on the continent. Those that failed to avoid floods were washed to sea. Some of them, floating on their own or traveling on natural rafts, are considered to have been the founders of the tortoise populations in the Galápagos Islands (Thornton 1971).

The extremely strong El Niño event of 1982-83

provides an answer to how tortoises could have dispersed among the islands. Due to the usual absence of rivers, and assuming it unlikely that a tortoise would enter the sea on its own volition, Thornton (1971) made the suggestion that dispersal of tortoises among the islands resulted from the unlikely event of a tortoise falling off a cliff into the sea and successfully making it to an adjacent island. However, observing the massive rivers of this past El Niño, and imagining tortoises at much greater densities and often near the coast prior to their decimation by whalers and buccaneers (Townsend 1925; Thornton 1971), it seems more probable that over the thousands of years, tortoises have periodically been washed into the sea and successfully arrived at other islands during major El Niño events.

Conclusion

Extremes in weather conditions do not appear to have a major effect on giant tortoise populations. In dry periods and during El Niño, tortoises maintained their normal behavior patterns, shifting the amount of time spent in each activity according to weather and availability of food and water. The only major change observed during El Niño was the mass migration of tortoises to lower elevations on Santa Cruz. During periods of drought, the scarcity of food and water may place a high cost on the individual. However, the ability of giant tortoises to live for periods of greater than one year and sometimes up to two years without food and water, as recorded in logbooks of whalers (Townsend 1925), suggests that tortoises could withstand long periods of drought. The longevity of tortoises, their low energy requirements, and low mortality rates of adults (e.g., during this study, no tortoise mortality was observed in any of the study areas) enable them to survive extremes in weather conditions which

may create "bottleneck" situations for other species. Many populations of terrestrial species in the Galápagos are severely reduced during periods of drought, while most marine species are severely reduced during El Niños (see articles by Grove and Robinson, this volume). While it is possible that either droughts and/or El Niños may negatively affect nesting of tortoises, or emergence and survival of hatchlings, the longevity of tortoises allows them to "wait" through bad periods without serious long range effects on the population.

El Niño rains and flooding effected increases in some plant species, while harming or temporarily eliminating others. More species were observed during El Niño than in the previous year and a half, however, few of the additional species were of major importance. In general, the majority of species which disappeared were in areas which were completely flooded, usually by ponds. As seen throughout the islands, there was a huge increase in vines, and a major decimation of *Opuntia*. The latter may ultimately have the greatest effect on tortoises, especially if this El Niño is followed by a long period of drought. However, with tortoise populations much reduced due to the decimation of the last two centuries, the effect may be less important than it would have been historically.

The effects of El Niño on vegetation in tortoise habitats was more important in terms of delineating between community types than any overall changes in species composition. In the Transition/*Scalesia* Zone, between major El Niño events there appears to be a relaxation period where merging of habitats occurs, creating indistinct borders between them. El Niño floods, causing mortality of those species which spread into neighboring habitats, will periodically recreate distinct delineations between habitat types. This phenomenon may also be important in other areas of the islands.

To have been in the Galápagos Islands during this great El Niño event was indeed a formidable experience. The impact of big El Niño events is perhaps most readily seen in the large canyons or encañadas of many of the islands, and perhaps we should have been forewarned. In early June 1983, I spoke with Alf Kastdalen, one of the early Norwegian settlers on Santa Cruz, of this year's El Niño. Though he had never seen one this strong, he said, "A year like this happens one in 100, maybe one in 200. The landscape shows that years like this have occurred in the past. The landscape shows it. The landscape shows it."

Acknowledgements

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TWELVE DAYS AMONG THE "VAMPIRE FINCHES"*
OF WOLF ISLAND

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Summary

A twelve day visit to remote Wenmann Island (Wolf) to film the wildlife, especially the blood-sucking finch, *Geospiza difficilis septentrionalis*, is chronicled. The visit coincided with the initiation of torrential rains preceding full development of El Niño conditions in the Galápagos. This article describes the experience.

Resumen

El artículo reseña una visita de doce días a la isla Wolf, visita en la cual se filmó la vida natural de la isla, incluyendo a los "pinzones chupadores de sangre". La visita coincidió con el inicio de las lluvias torrenciales, precursoras de un año de "El Niño". La narración describe la experiencia.

Some 80 nautical miles to the northwest of the main group of the Galápagos Islands, roughly 180

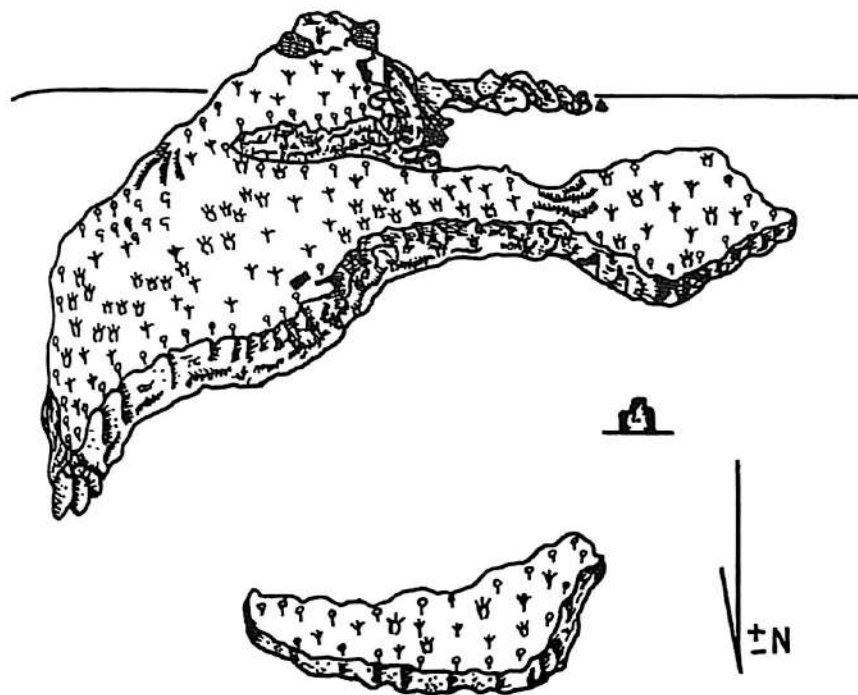
* Reprinted with modification from Noticias de Galápagos (1983) 38:4-10.

miles from Puerto Ayora on Santa Cruz, a huge volcanic rock emerges from the deep blue of the encircling waters. Wenmann, or Wolf, according to its official Ecuadorian name, is definitely one of the most inaccessible islands of the archipelago. With its highest peak rising to 253 meters, protected by steep basaltic cliffs, battered at their base by enormous oceanic swells, the island has rarely been visited by men.

However, when members of the University of California International Expedition to the Galápagos Islands in 1964 were landed by helicopter on one of its lower plateaus, Raymond Fosberg, a botanist, Robert Bowman and Stephen Billeb, ornithologists, discovered a most unusual and, so far as is known, unique feeding behavior among birds - the blood drinking habit of the Sharp-beaked Ground Finch, *Geospiza difficilis septentrionalis* (Bowman & Billeb 1965; Fosberg 1965).

Since then, the few scientific parties that have set out to conquer Wolf Island have had to make do without a helicopter and have had to jump and climb ashore amidst crashing breakers, clinging to cracks and holes in the slippery rocks in constant danger of being washed out to sea. Most of those who succeeded and safely reached one of the two lower plateaus on the northern end of the island (Figure 1) have been able to observe the "vampire finches" pecking at the bases of growing feathers on the "elbows" of Masked Boobies (*Sula dactylatra granti*) or the tails of Red-footed Boobies (*Sula sula*), causing them to bleed and then sipping the blood. In addition to the pictures published by Bowman & Billeb (1965), several still photographs of the blood-sucking birds have been taken, but as far as we know, only one or two attempts have ever been made to film this fascinating behavior. As these attempts failed for various reasons, such as inability to find a safe landing site, lack of time, or arrival at a time of

Fig. 1. By combining a map by Daniel Weber (D. Weber-Galapagos-12.3.1970) with some of our photographs, experience and imagination, we have produced an aerial view of Wolf, such as a bird approaching the island from the north would probably see.



- Y *Croton* sp., main breeding area of Red-footed Boobies and Frigatebirds;
- W *Opuntia helleri*, breeding area of finches and mockinbirds;
- Q *Erythrina velutina*, migrating Summer Tanager and two Vireos were seen here;
- P *Alternanthera helleri*, breeding areas of Masked Boobies and feeding sites of the "Vampire Finches";
- Camp

The distance between the eastern tip of "our" plateau and the outermost end of the lower platform to the west measures approx. 200m.

year when the peculiar behavior was not being exhibited, we felt the challenge to document the "vampire finches" on film was too great to be resisted.

When we learned of a reconnaissance trip by the Naval Oceanographic Institute of Ecuador and the National Institute of Galápagos (INGALA) to the northernmost island, Darwin, which would pass close to Wolf, we jumped at the chance to visit this remote island. Thus, at 5 am on November 7, 1982, we left Puerto Ayora aboard the M/Y Ingala II in high spirits

Just a few days before, a new battery for our Arriflex camera and the necessary film had arrived. Every piece of equipment had been double-checked and tested. Tents, sleeping bags and all those numerous items of camping equipment had been carefully packed. Most important for a stay on a waterless island, twelve "chimbuzos" (large water containers) were filled at the Darwin Station and hauled aboard.

The following is our diary of the 12 days we spent filming on Wolf Island, among Masked and Red-footed Boobies, Frigate Birds, agile centipedes, soft-spined cacti, slender *Croton* trees and - of course - the strange blood-sucking finches.

7 November 1982

Dawn marks the start of our journey. The first stop is the military base on Baltra Island. It takes four hours to fill the ship's tanks and many extra barrels with fuel for the long journey; then we are on our way to the two northernmost islands of the Galápagos archipelago, Wolf and Darwin, known on the old maps as Wenmann and Culpepper. At dusk we cast anchor on the northwestern coast of Pinta Island where a huge swell from the open sea rolls incessantly against the dark and jagged cliffs. A tiny fishing boat from San Cristóbal rides alongside,

enveloping us in a powerful odor of fresh and dried fish. Its deck is crammed with buckets, buoys, fishing lines and other equipment, between and on top of which ten or twelve men can be seen huddling around a miserable lamp. The scene makes it easy to imagine the countless hazards and hardships that these men must endure while visiting the fishing grounds for stretches of a month or longer.

8 November

One o'clock at night, we leave Pinta Island and head for Wolf. As the sun rises, groups of Masked Boobies can be seen all around our ship, gliding just above the smooth water. From now on we are permanently accompanied by bands of juvenile Red-footed Boobies.

At seven in the morning we eventually arrive at Wolf, its towering cliffs dwarfing our ship while we anxiously search up and down the northern coast to find a possible landing site amongst the green, foaming surf that beats against the rocks. Although discouraged by both the size of the pounding waves and the premonition of our dinghy being swamped by the backwash during an attempt to jump ashore, we decide to try a landing on a large rock that overhangs the swirling waters. We succeed. As if lifted by an elevator, the long swells heave our Zodiac, with all the precious equipment, within reaching distance for just a few decisive seconds, before it drops back again, out of reach far below. It takes half a morning's hard work before everything is put ashore and safely stored in rocky caves, high up where no waves could possibly reach. A few minutes later, we see M/Y Ingala II disappear into the blue distance towards Darwin Island barely visible to the north.

The afternoon is spent carrying camping and camera equipment to the top of the eastern plateau, climbing over rocky terraces, through dense fields of soft-spined cacti (*Opuntia helleri*) and along clefts and cracks in the rock walls. At sunset our camp is set up at the edge of a bare cliff, overlooking the wide sea to the north. It is surrounded by courting and nesting pairs of Masked and Red-footed Boobies and protected to the south by a dense stand of low and slender trees (*Croton scouleri*). Beyond, the highest peak of the island forms an impressive silhouette against the darkening sky.

9 November

Walking through the booby colony early this morning we notice several birds with stains of dried blood on their wings and many Sharp-beaked Ground Finches hopping and flying about. Several of them scratch the loose ground in what appears to be the "bill-bracing technique" reported for the Large Cactus Finch (*Geospiza conirostris*) and the Small Ground Finch (*Geospiza fuliginosa*) on Española Island (DeBenedictis 1966). A little later we observe our first "vampire finch" at work. Riding on the lower back of a booby and clinging to the large flight feathers on its folded wings, the finch repeatedly buries its beak deep into the formerly white feathers of the "elbow" which is now distinctly red with extruding blood. Watching from within a couple of yards, we can clearly see the blood being sipped into the closed beak of the finch as if through a drinking straw.

In the afternoon, M/Y Ingala II surprisingly returns from Darwin Island. Five of its men climb up to our camp site and then move on to inspect the interior of the island. At night we can see their camp fire through a drizzling rain. Later, the rain increases in strength as does the

midnight a full-blown storm is clattering and beating on our tent.

10 November

Our visitors tell us that only one member of the INGALA party had succeeded in jumping ashore on Darwin Island the day before. In the afternoon, shortly after M/Y Ingala II has finally departed, the heavy rains begin again. Worried about adequate protection for the camera and other equipment, we climb down the cliffs in the pouring rain to bring up one of our large aluminum cases in which to store everything safe from the deluge. The rains last all night. We find ourselves camping in the midst of a mud puddle.

11 November

In the morning we find that the frequent crashes heard during the night were *Croton* trees uprooted by the storm. A large bucketful of rainwater has collected in the folds of our tent roof, saving us a climb down to the rocky shore where our water provisions are stored. Our camp has now become the home and favorite foraging ground for two Cattle Egrets (*Bubulcus ibis*). Walking gracefully over our pots, tins, cases and backpacks with their long legs and slender toes, they move with incredible precision, catching flies and hunting the geckos (*Phyllodactylus gilberti*) which are quite common among the rocks.

Much to our surprise, with the exception of recent colonizers of the Galápagos, no other day creatures, nor even the finches and mockingbirds, both numerous around the camp, show any interest in our kitchen. Not even the ants are attracted by this new source of food. Foot-long centipedes (*Scolo-*

pendra galapagoensis), however, are a nuisance. Slowly crawling about at night, when frightened they swiftly dash for cover and are usually found in the morning curled up in our cooking utensils or food cans.

While drizzling rains and undiminished winds prevail during most of the morning, the sunny afternoon finds us at last filming "vampire finches" and their victims on the western cliffs. From up here, with the green and white breakers crashing against the dark rocks far below, the island's impressive landscape and the expanse of the open sea is viewed. Hundreds of Masked Boobies that nest along all the clifftops are floating through the air. Taking off in search of food or landing at their nesting sites, they are forced by the wind into spectacular flight maneuvers. Light conditions are just perfect, so we make the most of our chances and shoot some film in slow motion.

12 November

Again, it rains all night and during most of the day. By now, all the downy young and nestlings of the Masked Boobies have been seriously affected by the wet and cold. Shivering, with water incessantly from the tips of their lowered bills, drenched to the skin, the tougher ones manage to keep themselves upright, similar to penguins weathering a snow storm, while the weaker ones lie motionless on the soaking ground, waiting for the rain to stop or death to come. Many of the parents have not been back since the previous day to feed their young and we find several that have not survived the wet and chilly night. Patrolling Frigate Birds (*Fregata minor* and *F. magnificens*) take some of the smaller chicks but most corpses are left to the Sally Lightfoot crabs (*Grapsus grapsus*) that populate even the upper reaches of the cliffs and which turn out to be very

efficient scavengers. Much to our surprise we find these crabs to be generally dark in color instead of the bright red that is so typical of the larger individuals of other Galápagos populations.

13 November

It is late afternoon before the sky clears again allowing us to shoot a beautiful scene from the peak of the narrow ridge that separates the lower northern part of the island from its southern, higher plateau. Far below we see the larger, eastern plateau with hundred of Red-footed Boobies nesting in the *Croton* trees. The cliff edge is lined by thousands of white dots which, in reality, are thousands of Masked Boobies. To the west, a smaller peninsula, shaped like a snake's head, protrudes into the sea. The sky, colored by the sinking sun, proves a dramatic backdrop for the numerous Boobies, Frigate Birds, and Audubon Shearwaters (*Puffinus inhemieri*) flying both above us and far below.

Climbing down the ridge again, we watch a Red-footed Booby on its nest in a *Croton* tree being bled by two finches perched on its tail. The booby is a white-phase individual of this normally chocolate-brown species, so the blood stains on its white tail feathers stand out strongly. Later, while on our way back to camp, we hear and see a group of five Sooty Terns (*Sterna fuscata*) flying high above. They must have come here from Darwin, their only nesting ground in the Galápagos.

14 November

While tape-recording the voices of the awakening colony of Masked Boobies at dawn, we come across a dozen Sharped-beaked Finches hopping about and fighting over a broken booby's egg whose contents they

drink. A little later, near the same place and with our camera set, we observe a most fascinating behavior: Several finches manage to steal a booby egg from an unguarded nest by pushing and rolling it away. Two of the finches are especially adept at this. While the brown-feathered individual uses its bill purely as a lever, shoving it under the egg and lifting, the black individual anchors its bill in the soft ground or against a nearby stone and kicks the egg forcefully with both its feet at the same time. With this fine demonstration of the "bill-bracing technique" mentioned earlier, the finch succeeds in pushing the egg away from the nest. Other birds of the group now and then join in the enterprise and in less than an hour the egg has travelled some three meters. It eventually comes to a rest between two rocks but the birds continue pushing, kicking and levering so that the egg is turned and rolled around on the spot. We hear the sharp noises of the shell being repeatedly knocked against the rocks. Now and then, the finches stop to inspect their work, presumably looking for holes or cracks. Finally, a tiny opening in the shell, just enough for the tip of a bill to be inserted, marks the start of frantic fighting. All the finches of the group try to get possession of the egg. Within seconds ten or twelve beaks have chipped a large hole into the shell and all the birds crowd round drinking the liquid. When eventually the egg rolls over, spilling the rest of its contents on the ground we see two or three finches, in what could be called a feeding frenzy, viciously fighting over the tiny embryo which they drag out of the egg, ripping it to pieces on the spot.

We now understand the reason for the many "lost" booby eggs that we have seen and the fact that many of them had large holes or were broken. The Sharp-beaked Ground Finches of Wolf Island are not only blood-sucking "vampire finches", but skillful egg robbers as well.

15 November

For the third time during our stay on Wolf, we observe a large group of 80 to 100 juvenile Red-footed Boobies engaged in what appears to be a curious communal game. Flying high in a rather dense formation and calling our attention with their harsh voices, they are seen to pass a "toy" from one to the other. Even with the use of our fieldglasses we cannot detect the precise nature of the "toy". It might be a feather, a leaf or a stick. It is held in the beak by one bird and carried a little upwards in the circling cloud of birds; then it is dropped. After a few seconds of free fall, it is caught by a second bird and carried upwards, only to be dropped again and subsequently picked up by yet another bird and, thus, the process continues.

The game, if we may call it so, always started near the summit of the island. The wind then carried the cloud of birds and their "toy" out to sea, where they eventually settled on the surface near the spot where, after numerous passes, the "toy" had finally fallen on to the water. A few days before, while climbing the peak, we had seen a juvenile Red-foot holding a long feather in its beak. Descending an hour later, we found it still holding the feather. Will it fly, we speculated, to join others and then drop the feather, initiating a new game? Looking under nesting and roosting places of Red-footed Boobies on Wolf, we found the following objects: 3 short plastic thongs, 1 toy basson, all made of bright, blue plastic and between 6 and 10 cm long. Were these the boobies' "toys"? How else could these strange objects have made their way to the top of Wolf Island?

16 November

Today, torrential rains and thick clouds hanging low over the sea force us to leave our camera in its case. No boobies are seen flying anywhere. Crowding along the cliff edge, their numbers seem to have doubled. As they stand motionless next to their unprotected young, the adults seem totally unaffected by the pouring rain. The downy chicks, however, become soaked and again we find that many have died. The only creatures that seem to enjoy the rain are the Frigate Birds. Gliding up and down high above the island, they appear, literally, to bathe in the air. Diving vertically and vigorously shaking their wing and tail feathers, at times they completely disappear into the clouds.

Taking the opportunity offered by a few moments without rain, we catch a Masked Booby with a prominent blood stain to see whether the blood-drinking habit of the finches has any harmful effect on the growing feathers. No deeper probe than a simple visual inspection is possible, but from this we conclude that there is no direct harm to the young feather even though the blood-filled quills are punctured by the finches and partially drained of their blood. More detailed study, however, may well prove worthwhile.

We were surprised to see that most boobies do not react vigorously against the finches. Courting pairs seem virtually unaware of the "vampires" riding on their backs, pecking and drawing blood from their feather quills. With single boobies, however, a reaction of discomfort can frequently be observed. After several minutes of restlessly walking around on the cliff, now and then shaking their wings to throw off their relentless pursuers, they take flight on a direct course out to sea. On stiff wings they glide down to the water, where, after a shallow dive, a long wake of white foam marks the end of their

deal. Usually, an extended bath with much wing-shaking, preening and roosting over ensues. The boobies, washed of blood stains, may return to their places on the cliff to enjoy a period of peace before being pestered by the finches again. Finches apparently choose their victims by keying-in on boobies with blood stained feathers.

On more than one occasion we have come across a group of finches parasitizing Masked Booby nestlings of various ages. While adult boobies may escape from their persecutors, downy young and flightless juveniles cannot. Crouching on their heels with the neck being prominently arched and the beak tucked away under the body in the characteristic submissive position, the downy chicks are totally defenseless. Many of these young show bloody cuts and scratches along the bare sides of their necks, presumably the result of rather rough handling by their parents or other adults. Quite frequently we observe an adult clasping the neck of a chick with its beak and shaking it for a few seconds. The sharp cutting edges of the adult's bill produce at least some of the cuts and scratches that we have seen. These rapidly become an attraction to the finches. Downy young at an early age do not have blood-filled feather quills to offer and thus seem to suffer mostly from attacks on their bare necks. Larger chicks, with feathers already protruding on their wings and tails, are primarily parasitized at their tails. It is saddening to see how these comparatively large birds try to rid their tormentors by desperately walking backwards and forwards across the nesting area, but relentlessly followed by a group of Sharp-beaked Finches pecking at their bloody tails.

17 November

It rains all day long. Our tent, built on arid ground with scanty vegetation less than two weeks ago, is now surrounded by fresh green *Alternanthera helleri* bushes. The bare *Croton* trees are now covered with green leaves; *Opuntias* and the beautiful *Portulaca howelli* are all in flower. Behind our camp, low in the scrub of *Alternanthera* bushes and flowering cacti, we find many dome-shaped nests built by "vampire" finches and lined with white booby feathers. The birds are feeding on the filaments of *Opuntia* flowers and hunting for insects under the loose bark of dried and fallen trees. It is in this area, which gradually changes from an open cactus field into a dense *Croton* stand, that we eventually manage to film some of the far less numerous Large Ground Finches (*Geospiza magnirostris*) and Warbler Finches (*Certhidea olivacea*) which we have seen only rarely near our camp on the cliff.

18 November

It is afternoon before the heavy rain changes into a steady drizzle. Most of the sea birds have left by now in search of food for themselves and their young, many of which endure these difficult conditions standing in shallow mud puddles, stoically awaiting their parents' return. Finches and mockingbirds (*Nesomimus parvulus*), on the other hand, seem to be having a great time. Busy with singing, territorial fighting, nest-building and courting, they all prepare to make optimal use of the conditions resulting from the rains.

In the evening, while on our last trip on the western cliffs, the wind changes direction and rain becomes heavier again. Within seconds we are soaked. Coming back to the camp, we find our shelter toppled over by the wind. Even our lunch has not escaped and tastes too watery to be any good.

19 November

Our last day on Wolf Island. It is one of the few days of fine weather. As some introductory shots are needed for our film, we climb down the cliffs to the rocky shore where several pairs of the Great Frigatebird (*Fregata minor*) have their nests and young. Halfway down, in little caves along the foot of the steep rockwalls, we find what appear to be old nests of the Galápagos Dove (*Zenaida galapagoensis*) which is quite common around our camp. Well hidden behind a large stone in a hole in the cliff, we discover a Red-billed Tropicbird (*Phaeton aethereus*) with its yellow-billed young.

In the afternoon we walk over leaf-littered ground in a small grove of *Erythrina velutina* trees near the eastern cliff. This group of comparatively large trees contrasts strongly with the low stands of *Croton* forest and seems to be rather out of place here. In its shade we find large stones and rocks, uprooted trees and rotting logs which had doubtless been carried to this place over many years by huge floods of rainwater that had come down from the peak, cutting an impressive creek bed through the grove. On a twig in the grove, a Large-billed Flycatcher (*Myiarchus magnirostris*) perches and not far from it, the greenish female of the Summer Tanager (*Piranga rubra*), a migrant from North America, is resting in the shade. At the edge of the grove two other birds attract our attention. Our best efforts at identification lead us to conclude that they must be Red-eyed Vireos (*Vireo olivaceus*), migrants from the north as well. As far as we know, this species has not previously been reported in the Galápagos.

Summing up the migrant birds that we have noted on Wolf: 5 Cattle Egrets (*Bubulcus ibis*) were recorded near our camp throughout our stay; on 14 November, a cuckoo flew over our camp (*Coccyzus*

melacoryphus most likely); two White-cheeked Pintails (*Anas bahamensis*) crossed the northern bay on 15 November and on 17 November, numerous Bank Swallows (*Riparia riparia*) were seen flying along the edge of the cliffs. The only migrant marine species we saw was a Cape Pigeon (*Daption capense*) on 18 November, an antarctic breeder that migrates north.

20 November

At 7 am we hear the Darwin Station's M/Y Beagle IV cruising into the bay below. It takes us three hours to carry all our equipment down the steep cliff and over the slippery ledges to where the dinghy waits and another hour before all the precious gear and our invaluable film footage of the "vampire finches" is put safely on board.

We have documented on film the most unusual blood drinking and egg robbing habits of the Sharp-beaked Ground Finches of Wolf Island. We have had a lot of rain and poor light, with only a few sunny days, but we have certainly received a most incomparable Galápagos experience.

Several months have passed and it is clear that the most unusual rains we endured on Wolf were the precursors of an El Niño year. Every 7 to 10 years warm currents of the eastern Pacific, which normally stay north of the Galápagos, press southwards and prevent the cold Humboldt current from flowing north to the islands, thus changing the normal climatic pattern of the archipelago. The reasons for these changes are only poorly understood, though their drastic consequences are well known. Air and water temperatures are raised and frequent rainfalls quickly alter these barren and arid islands into lush green appearing paradises.

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RESPONSES OF DARWIN'S FINCHES TO
UNUSUAL RAINFALL

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Summary

Heavy rains began falling in early or mid--November 1982. They continued with little interruption until the middle of July 1983. All islands received more rain than ever recorded before, and probably more than in any other year of the century. On Isla Genovesa several species of plants had an extended flowering season. For example, *Croton scouleri*, which normally flowers once or twice, flowered five to seven times, and seed production was correspondingly enhanced. Other plant species (e.g. *Bursera graveolens*) flowered for the same length of time as usual, but earlier, and yet others (e.g. *Cordia lutea*) postponed their major flowering until after the rains had ceased.

Darwin's Finches began breeding on this island in late November or early December 1982, and continued until the end of July 1983. The breeding density of the Large Cactus Ground Finch (*Geospiza conirostris*) was 50 percent greater than it had been in early 1982, and greater than in any year since at least 1976. Some birds, including one-year olds, bred in areas and habitat not previously occupied by members of this species. Clutch sizes were typical, but fledging success was low owing to high

incidences of predation, probably from mockingbirds, and desertion. The most successful pair laid 29 eggs in seven clutches and fledged 20 young. Events on Isla Genovesa were probably typical of those in the archipelago, at least at low altitudes, although on Daphne Major finches bred for slightly longer (9 months) and experienced greater success.

Resumen

Las lluvias fuertes comenzaron a principios o a mediados de noviembre de 1982 y continuaron con pequeñas interrupciones hasta mediados de julio 1983. Todas las islas recibieron más lluvia de lo que nunca antes se había registrado y probablemente más que en ningún otro año en lo que va de este siglo. En la isla Genovesa, varias especies de plantas habían extendido su período de floración. Por ejemplo, *Croton scouleri*, que normalmente florece una o dos veces, floreció de cinco a siete veces y la producción de semillas consecuentemente aumentó. Otras especies vegetales (por ejemplo, *Bursera graveolens*) florecieron por un período normal de tiempo pero la época de floración se adelantó. Finalmente otras (por ejemplo, *Cordia lutea*) pospusieron su período principal de floración hasta cuando cesaron las lluvias.

Los pinzones de Darwin comenzaron a reproducirse en esta esla a finales de noviembre o a comienzos de diciembre de 1982 y continuaron hasta finales de julio de 1983. La densidad de reproducción del pinzón grande de tunal (*Geospiza conirostris*) fue mayor en un 50 por ciento con relación a lo que había sido a comienzos de 1982 y mayor que en ningún otro año desde 1976, por lo menos. Algunas aves, incluyendo a aves de un año de edad, se reprodujeron en áreas y hábitats que antes no habían sido ocupados por miembros de esta especie. El tamaño de las posturas fue típico, pero el éxito de la salida de los

huelos del nido fue bajo debido a una alta incidencia de predación, probablemente por parte de cubs, y por el abandono de los nidos. La pareja exitosa puso 29 huevos en siete posturas, de las cuales salieron 20 juveniles. Los eventos de la isla Genovesa son probablemente típicos de los del archipelago, por lo menos en cuanto se refiere a áreas de baja altura, aunque en Daphne Mayor los pinzones se reprodujeron por un período ligeramente mayor (9 meses) y tuvieron mucho éxito.

INTRODUCTION

The oceanographic phenomenon of El Niño, that is, unusually high sea surface temperatures, began in Galápagos in October 1982 (Smith, 1983). Rainfall, a correlated meteorological effect, began about the middle of the following month. Rains continued into the middle of 1983. The last heavy rain fell on I. San Cristóbal on July 13, on I. Santa Cruz on July 17, and on I. Genovesa on July 21. The length of the rainy period (8 months) and the amount of rain that fell exceeded all previous records for the Galápagos.

The heavy and extensive rains produced substantial ecological effects upon the terrestrial vegetation and fauna. In this chapter we will describe the effects of the El Niño event of 1982-83 upon the breeding of Darwin's Finches. We will concentrate on the large cactus ground finch, *Geospiza conirostris*, on Isla Genovesa because this population has been studied intensively since 1978. In the Discussion we compare this population with the only other populations studied intensively in 1983, namely *Geospiza fortis* and *G. scandens* on Isla Daphne Major.

We will first document the pattern of rainfall, then describe the responses of the vegetation and finally outline the demographic changes exhibited by *G. conirostris*. This follows a causal sequence suggested by previous work (Abbott et al., 1977; Smith et al., 1978; Grant and Boag, 1980; Grant and Grant, 1980a, 1980b; Millington and Grant, 1983): the onset, amount and duration of rainfall determines the growth, flowering and fruiting of the vegetation; the vegetation determines the survival and reproduction of the finches, both directly and indirectly through the arthropods it supports.

RAINFALL AND TEMPERATURE

Fig. 1 shows how unusual it was for rain to start falling November and to continue into the following July. The data were collected on I. Santa Cruz.

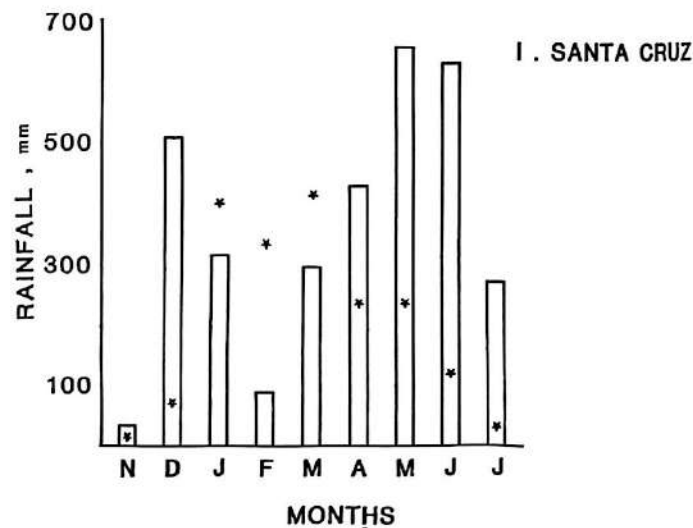


Figure 1. Rainfall recorded at the Charles Darwin Research Station, Isla Santa Cruz, in the period November 1982 to July 1983. The maximum rainfall recorded in those months in the preceding 18 years is shown by stars.

Our first data for I. Genovesa were collected as recently as 1978. In the short time since then we have never received a report of rain on the island before January.

The Figure also shows what an extraordinary amount of rain fell at the coastal station on I. Santa Cruz (3258 mm), nearly four times as much as the largest amount recorded in the same months in any of the preceding 19 years (888 mm in 1974-1975). The amount recorded on I. Genovesa, 2408 mm, was less, but still 14 times greater than in any of the previous 5 years (Fig. 2). In fact, the rainfall total is a minimum because when the island was first

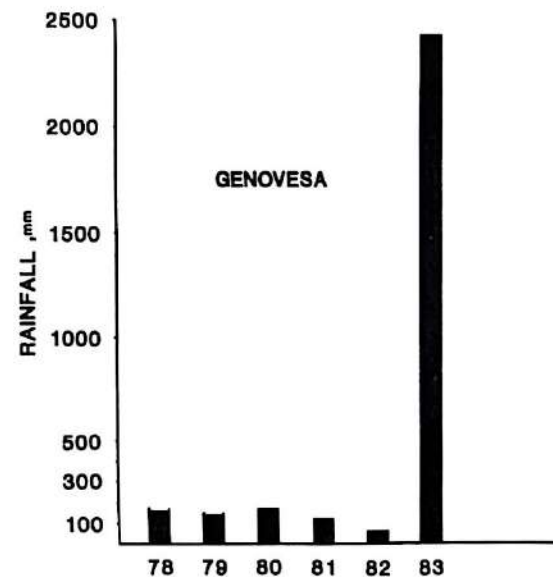


Figure 2. Annual rainfall on Isla Genovesa in the period 1978 to 1983. Exact totals are not known for 1978 and 1979 (see Grant and Grant, 1980a). Rain that fell in November and December 1982 has been added to the total annual for 1983, without adjustment for overflow and evaporation losses from the rain gauge.

visited by our assistants, on 31 December 1982, the rain gauge was overflowing; and water surely evaporated from the gauge after some of the November and December rainfalls.

The pattern of monthly variation in rainfall on I. Genovesa is shown in Fig. 3. The bimodal distribution in time is also seen in the rainfall pattern on I. Santa Cruz (Fig. 1) and has been noted occurring on this island in several other years (Grant and Boag, 1980). In contrast to I. Santa Cruz, the month of heaviest rain on Genovesa was the last, July, and the rain all fell in the first 21 days of the month.

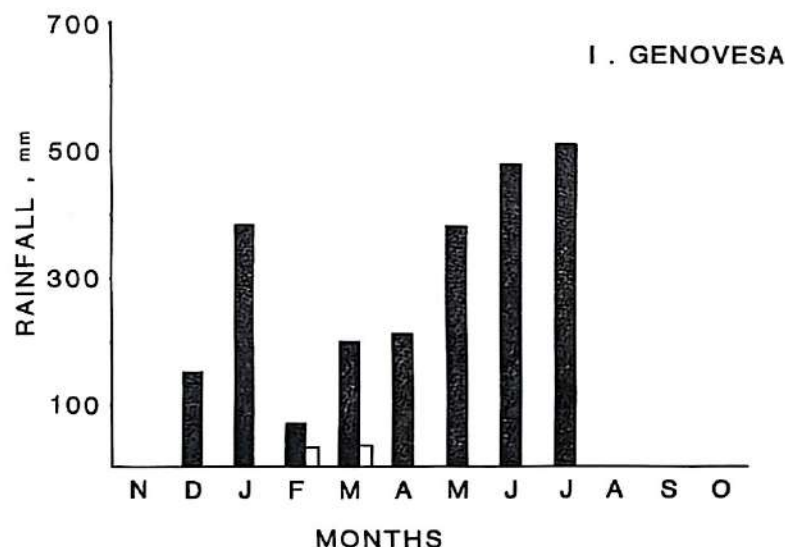


Figure 3. Monthly rainfall on Isla Genovesa in the period November 1982 to August 1983. The December value is a composite of November and December values and is an underestimate (see Fig. 2 legend). The open bars represent the total rain that fell in the first seven months of 1982.

Rain fell on the island for 11 consecutive days, twice. This is placed in perspective by a comparison with 1978, an apparently typical year. In that year rain fell in the period January 10 to April 23 on only 19 occasions altogether, and never on more than 4 consecutive days.

A final quantity of interest is the daily amount of rain. In a 25 hour period, 50 mm or more of rain fell on 13 occasions in 1983, but only once in 1978. The heaviest rain fell in the last 24 hour period of the rainy season: the total was 153 mm.

Daily maximum and minimum shade temperatures were also unusually high in 1983, but comparable data for I. Genovesa are only available for 1982 (Fig. 4). For example, the maximum reached or exceeded 36°C on 74 occasions in 1983 in the months of January to July, but on only 7 occasions in 1982. The highest temperature recorded in 1983, 39.6°C, was 2.6°C higher than the maximum recorded in 1982 (R.L. Curry, pers. comm.).

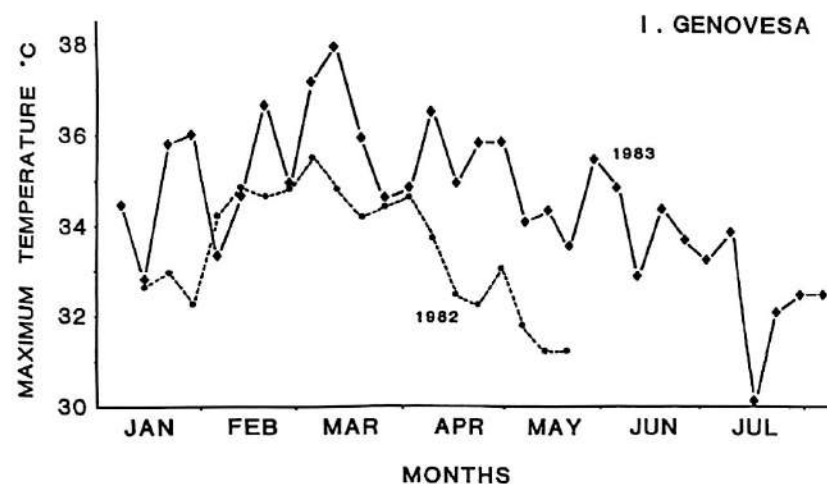


Figure 4. Daily maximum shade temperatures at the camp on Isla Genovesa, 15 m above sea level; they are expressed as weekly averages.

VEGETATION

Species. Wiggins and Porter (1971) refer to 38 species of land plants on Genovesa. We have recorded all of these except two: *Pectis tenuifolia* and *Aristida repens*. In 1978 we recorded an additional 10 species (Grant and Grant, 1980a), although we misidentified *Evolvulus simplex* as *Cuphaea carthagenensis*. The list of 48 species that includes this error is given in Grant and Grant (1980a). A single specimen of a *Cassia* species was found in July 1980, bringing the corrected total to 48 species.

In 1983 we recorded four more species. A single specimen of *Ipomoea pes-capra* was found at the top of the main beach in Bahia Darwin. A small clump of *Desmodium canum* was found, but the other two species, *Digitaria horizontalis* and *Eleusine indica* both grasses, were represented by several individuals. All four species were found in places frequented by visitors, so although the species total for the island now stands at 52, these last four additions may have had an anthropogenic origin.

More than 200 seeds of *Hippomane* were found on the shore. This species is not present on the island. Approximately 50 seeds of *Erythrina velutina* were also found, and these too had probably been washed in from another island because they were found on a beach far from the only known tree on Genovesa.

Phenology. Sufficient rain fell in November 1982 to induce leafing response from the major trees and shrubs in the third week of that month (D. Day, pers. comm.). In the period 1977 to 1982 the initial leafing response to rain was in the months of January, February or March. Therefore the season of major primary production began two months early in 1982-83.

Flowering phenology in the first eight months of 1983 is illustrated in Fig. 5 in comparison with

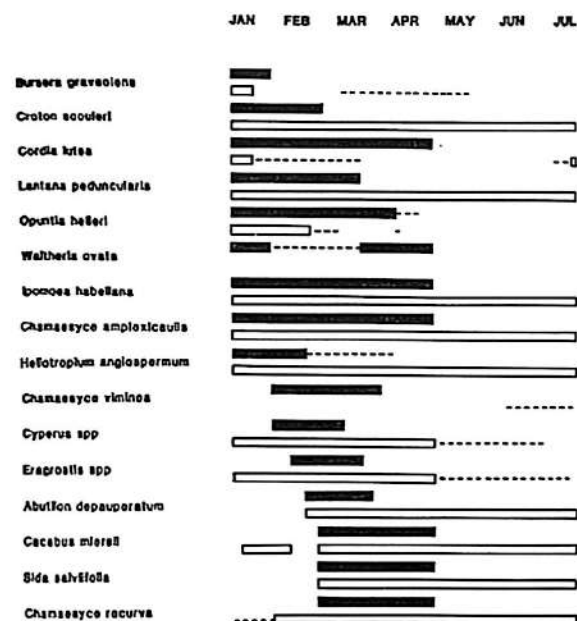


Figure 5. Flowering phenology of the plants on the study area of Isla Genovesa in 1978 (closed bars) and 1983 (open bars). Broken lines indicate rare and sporadic flowering.

the phenology in 1978, an apparently typical year. Three classes of plants may be recognized. The first is a group which showed no unusual response to the extended rains of 1983. It comprises *Bursera graveolens* and *Opuntia helleri*. Figure 5 appears to indicate an early cessation of flowering of these species in 1983, but since the onset of flowering (not shown) was also early the length of the flowering season was not unusual.

The second group had an extended flowering season in 1983. This group includes *Croton scouleri*, *Lantana peduncularis*, *Heliotropium angiospermum*, *Cyperus* spp., the principal grass species *Trichoneura lindleyana* and *Eragrostis* spp., *Abutilon depauperatum* and *Sida salviifolia*. Some individuals of these species were still flowering at the end of our study

on August 5, and on the day (August 19) of a brief return to the island.

The third group did not flower, or flowered only for a short time, at the time of the year when they normally do flower. This group comprises *Waltheria ovata* and *Cordia lutea*. *Waltheria* normally flowers sporadically when it is wet, prolifically when it is dry. In 1983 no flowering was observed in the first seven months, and only one bush was seen in flower in August. *Cordia* normally flowers occasionally during the wet season and then prolifically at the end of the wet season and into the dry season. The extended rains of 1983 postponed the strong flowering response of this species until the last week of July.

Cordia lutea (group 3) and *Croton scouleri* (group 2) make an interesting pair of species to compare (Fig. 6). In a typical year when the wet season lasts for two to four months there is extensive overlap in their flowering seasons, with *Cordia lutea* having the longer one. In the very wet year of 1983 the situation was reversed, with relatively little overlap in their flowering seasons and *Croton scouleri* having the longer one. This reverse came about as a result of very different responses to rainfall. *Croton scouleri* is an opportunistic breeder. Individual trees flower every one-two months for as long as it rains, hence they flowered five to seven times in 1982-83 in contrast to a normal one to two times. Even their offspring flowered! A seed in December 1982 was a 2 m tall flowering tree in May 1983 (R.L. Curry, pers. comm.)! In contrast *Cordia lutea* appears to breed in response to different and more restricted conditions (the end of the rains), although there is variation in responses among members of the population.

Production. The frequency of occurrence of plants in 50 randomly chosen 1 m² quadrats in the study

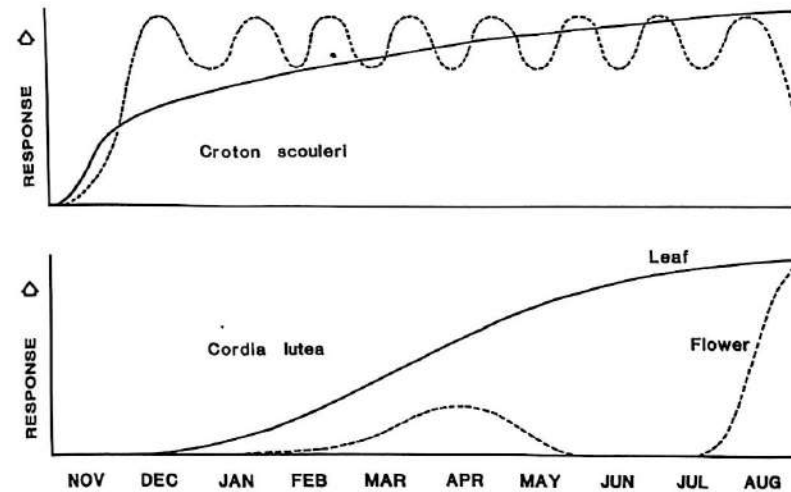


Figure 6. Schematic representation of the leaf growth (solid line) and flowering (broken line) of two dominant tree species in the study area on Isla Genovesa in 1983.

area had been determined four times prior to 1983 (Abbott et al., 1977; Grant and Grant, 1980a). Random sampling was repeated in July 1983.

Table 1 shows that *Heliotropium angiospermum*, *Lantana peduncularis* and *Cyperus* spp. were exceptionally abundant in 1983. Outside the sampled area, *Cacabus miersii*, *Merremia aegyptica*, *Ipomoea habeliana* and *Desmodium procumbens* were locally abundant: this is not reflected in the data from the sampled area (Table 1). Finally, two species of plants, *Eragrostis ciliaris* and *E. cilianensis*, might have been expected to develop abundant populations because in 1973, the year after another El Niño event, they were frequently encountered in the sampled area. However they were not unusually frequent in July 1983 (Table 1).

Table 1. Frequency of occurrence of plant species (%) in 50 random quadrats of 1 m²; x = presence elsewhere in the study area. Further details of the study area and methods are given in Grant and Grant (1980a).

Plant species	March 1973	Nov. 1973	March 1978	Nov. 1978	July 1983
<u>Cryptocarpus prifonius</u>	x	x	4	x	x
<u>Cordia lutea</u>	36	34	40	38	42
<u>Heliotropium angiospermum</u>	x	x	x	x	22
<u>Ipomoea habeliana</u>	4	x	x	2	2
<u>Ipomoea linearifolia</u>	2	2	2	x	x
<u>Narcissus asgyptica</u>	x	x	-	-	x
<u>Cacabus miersii</u>	x	x	2	-	4
<u>Lantana peduncularis</u>	8	x	4	2	26
<u>Bursera graveolens</u>	58	58	66	68	42
<u>Opuntia helleri</u>	8	6	20	20	16
<u>Oxynasysa angustifolia</u>	2	x	x	x	x
<u>Oxynasysa repens</u>	4	x	2	2	2
<u>Oxynasysa yirinea</u>	x	x	x	x	2
<u>Cordia alliodora</u>	44	68	56	58	68
<u>Acacia drepanolobium</u>	4	x	2	-	x
<u>Peperomia polka</u>	x	x	x	x	x
<u>Valeriana ovata</u>	6	16	6	0	14
<u>Cyperus spp.</u>	x	x	x	x	10
<u>Persea spp.</u>	16	2	-	-	2
<u>Eleusine indica</u>	4	-	-	-	0
<u>Sida salviifolia</u>	-	-	-	-	4

A complementary measure of abundance is provided by the average percent coverage of each plant species in sampled quadrats. The same method of estimating percent coverage was used in 1978 and 1983. A comparison of results from those two years is presented in Table 2. This illustrates more vividly than does Table 1 the greater luxuriance or thickness of the vegetation for almost all species in 1983, a fact that was obvious to the eye. Annuals were especially

Table 2. Mean percent cover of plant species i.e. an average of the summed percent cover of individual plant species in 50 random quadrats of 1 m² (not calculated when percent frequency was <2)

Plant species	March 1978	July 1983
<u>Cordia lutea</u>	5.5	29.2
<u>Heliotropium angiospermum</u>	--	8.2
<u>Ipomoea habeliana</u>	--	1.9
<u>Ipomoea linearifolia</u>	0.1	x
<u>Cacabus miersii</u>	0.1	5.3
<u>Lantana peduncularis</u>	1.2	11.4
<u>Bursera graveolens</u>	11.4	15.4
<u>Opuntia helleri</u>	10.1	11.0
<u>Croton scouleri</u>	13.2	33.1
<u>Waltheria ovata</u>	0.5	5.1
<u>Cyperus spp.</u>	--	3.9
<u>Eragrostis & Trichonoura</u>	0.2	2.4
<u>Sida salviifolia</u>	--	2.1

tall. For example *Abutilon depauperatum* and *Sida salviifolia* normally grow to a height of 0.5 m, but in 1983 the maximum height of both species was approximately 2 m.

Cordia lutea and *Croton scouleri* were still growing in July and August, after the rains had ceased. Ten shoots of *Cordia lutea* grew an average of 11.10 ± 1.43 cm (SE) between July 12 and July 25, then a further 7.38 ± 1.67 cm ($N = 8$) between then and August 5. Not only was distal growth occurring, leaves of both species appeared to be exceptionally large. The largest leaves on bushes or trees of both species were approximately 17 x 12 cm. No data are available on leaf size in other years for a quantitative comparison, however.

Production of fruits and seeds throughout 1983 was not monitored. Nevertheless a limited comparison between years is possible (Table 3) because the standing crop of seeds and fruits on plants was sampled in 1978 and 1983 (also in 1973; see Abbott et al., 1977). The comparison is weakened by the fact that sampling times were different in the two years, both absolutely and relative to the onset and cessation of the flowering season. Despite these problems the data in Table 3 show that some species of plants carried unusually large numbers of seeds in 1983. Although quantitative data are lacking, it can be readily appreciated that plants like *Croton scouleri* must have produced enormous crops of seeds in 1983; not only was the standing crop high in July, but it was the 5th, 6th or 7th to be produced that year.

The only species that might have fared poorly in 1983 was *Opuntia helleri* (Table 3). Fertile fruits were relatively scarce by the middle of 1983. In contrast to this species, two other plants, *Cordia lutea* and *Bursera graveolens* had low standing crops of seeds in the middle of the year (Table 3) for

Table 3. Numbers of seeds and fruits on the principal plant species in the quadrats, expressed as mean number per $m^2 \pm 1$ SE. A size-hardness index (DH)^{1/2} of seeds is given, where D = depth in mm and H = hardness in kgf. (see Abbott et al., 1977).

Plant species	(DH) ^{1/2}	March 1978	Nov. 1978	July 1983
<i>Cordia lutea</i>	13-14	5.9 ± 3.9	1.8 ± 0.6	0
<i>Opuntia helleri</i>	7-8	1.7 ± 0.8	1.6 ± 0.6	0.5 ± 0.05
<i>Bursera graveolens</i>	4-6	7.7 ± 2.8	0	0
<i>Ipomoea linearifolia</i>	3-4	0.5 ± 0.3	2.2 ± 1.6	0
<i>Lantana peduncularis</i>	2-3	38.7 ± 29.0	0	9.0 ± 2.8
<i>Heliotropium angiospermum</i>	1-2	0	0	37.8 ± 13.3
<i>Chamaesyce recurva</i>	1-2	0	0	20.0 ± 5.3
<i>Croton scouleri</i>	1-2	9.4 ± 2.7	0	15.7 ± 5.3
<i>Chamaesyce amplexicaulis</i>	0-1	x	0	0
<i>Sida salviifolia</i>	0-1	0	0	many
<i>Trichoneura</i> & <i>Eragrostis</i> spp.	0-1	129.3 ± 124.1	51.7 ± 32.4	many
<i>Cyperus</i> spp.	0-1	-	-	464.6 ± 184.4

easily discerned reasons: the fruiting of *Cordia lutea* had scarcely begun, and a large crop of *Bursera graveolens* fruits had been produced and then consumed or dispersed by birds.

Erythrina velutina provides the only example of a species that apparently requires exceptionally wet conditions to reproduce. Seeds, but no saplings, were found beneath the single tree on the island in the years 1978, 1979, 1980, and 1982. In July 1983 there were seven saplings beneath the parent tree, in addition to many seeds, they varied in height from 0.25 m to 0.75 m, and they were all in leaf.

FINCHES

Phenology. *G. conirostris* bred uninterruptedly throughout the extended wet season. The start of the breeding season can be estimated from the state of nests when our assistants arrived on the island on 31 December 1982, and from knowledge of the average lengths of the incubation and nestling periods (Grant and Grant, 1980a). From this information we calculate that the first egg was laid on 8 December. Since there were no newly fledged juveniles observed at the time of our assistants' arrival, we can be fairly sure that no successful breeding had been completed before this time. On the other hand, some eggs may have been laid earlier than 8 December and abandoned. The first heavy rain fell about three weeks before this estimated first date of laying (D. Day, pers. comm.). In 1978 the first egg was laid about one week after the first rains.

The end of the breeding season is known precisely. The last observed fledging occurred on 29 July, and possibly one more occurred two days later.

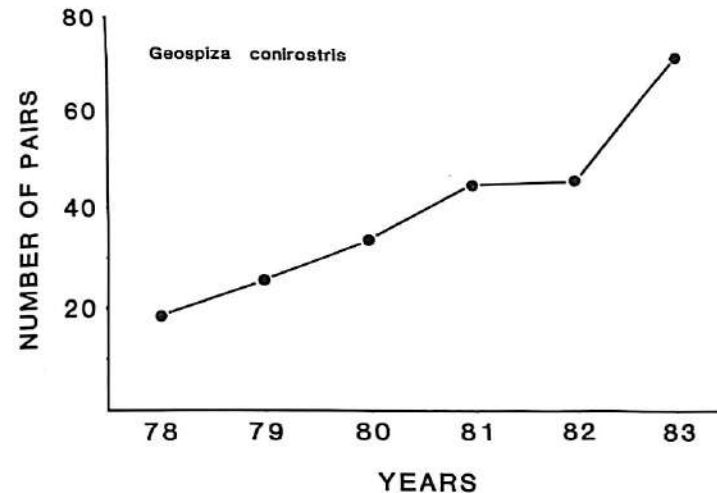


Figure 7. The increase in number of breeding pairs of *Geospiza conirostris* in the study area on Isla Genovesa from 1978 to 1983.

Thus the season from first egg to last fledging spanned approximately 248 days. This was much longer than in any of the previous years: 150 days (estimated) in 1978, 114 days in 1980, 85 days in 1981 and 98 days in 1982.

Density. Figure 7 shows that a marked increase in density of breeding *conirostris* took place in 1983. This came about through recruitment of new birds, mainly one-year olds, to the breeding population. Recruitment occurred gradually during the breeding season, and some birds did not settle to breed in the study area until May. The new breeders included one-year old males and females that were banded as nestlings in the previous year.

The breeding density in 1983 was three times higher than it was in 1978, which was the year following a drought (1977) (Grant and Grant, 1983). The sharp increase in maximum density in 1983 was

Table 4. Nesting success of *G. conirostris* in the study area in the years 1978 to 1983.

Year	Number of Nests Studied	Number Predated	Number Unsuccessful for other reasons	Percent Nests Successful
1978	41	3	4	82.1
1980	77	12	7	75.3
1981	92	2	13	83.7
1982	109	20	34	68.8
1983	237	82	38	49.4

not accompanied by a reduction in average territory size. Rather, territories were established in areas that were previously not occupied by *conirostris* (Grant and Grant, 1979, 1983). These areas had little or no cactus.

Nest Placement. As a consequence of the establishment of new territories in a somewhat different habitat, a distinct shift took place in the use of vegetation for nesting. In 1978, for example, 95 percent of all *conirostris* nests were placed in *Opuntia* cactus. In 1983, on the other hand, only 43 percent of all *conirostris* nests were placed in cactus, the remainder being in *Cordia lutea* (28 percent), *Croton scouleri* (22 percent) and *Bursera graveolens* covered by *Merremia aegyptica* or *Ipomoea habeliana* (7 percent). Pairs that held territories rich in cactus also contributed to this shift to a small extent.

Breeding Success. Despite the extended breeding season, reproductive success overall was surprisingly low. The data that show this are given in Tables 4 and 5. Table 4 shows that nesting success was unusually poor. This can be largely attributed to pre-

Table 5. Production of eggs, nestlings and fledglings of *Geospiza conirostris* in the study area in the years 1978 to 1983 for those pairs studied fully (in 1979 the island was visited for only one month).

Year	Number of Pairs	Mean Number per Clutch			Number of Clutches	Number of Young per pair
		Eggs	Nestlings	Fledglings		
		$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$	$\bar{x} \pm SE$
1978	15	4.1 $\pm$ 0.1	3.1 $\pm$ 0.2	2.7 $\pm$ 0.2	3.1 $\pm$ 0.2	7.9 $\pm$ 0.7
1980	35	3.4 $\pm$ 0.1	2.6 $\pm$ 0.2	2.1 $\pm$ 0.2	2.2 $\pm$ 0.1	4.6 $\pm$ 0.4
1981	46	3.5 $\pm$ 0.1	3.2 $\pm$ 0.2	2.2 $\pm$ 0.2	2.0 $\pm$ 0.1	4.5 $\pm$ 0.4
1982	44	3.3 $\pm$ 0.1	2.3 $\pm$ 0.1	2.0 $\pm$ 0.2	2.6 $\pm$ 0.1	4.9 $\pm$ 0.4
1983	15	3.4 $\pm$ 0.1	1.7 $\pm$ 0.2	1.3 $\pm$ 0.2	6.8 $\pm$ 0.3	8.1 $\pm$ 1.2

dation. Predation of eggs and nestlings by Mockingbirds, *Nesomimus parvulus*, and of nestlings by Short-eared owls, *Asio flammeus*, has been recorded in previous years (Grant and Grant, 1980a, 1983). In those years the owl has been suspected of being the major predator, but in 1983 the signs remaining after the destruction of nests implicated mockingbirds. Few nests had collapsed roofs, which is the hallmark of owl predation. Additionally some nests were abandoned in heavy rain, and the earliest clutches formed possibly in late November and early December may have suffered in this way too.

The effect of mockingbird predation on eggs is manifested as a particularly low mean number of nestlings per nest (Table 5). For those 15 pairs studied fully, i.e. followed from the beginning of the breeding season to the end, mean clutch size was about the same as it had been in the three previous years, but the average brood size was markedly reduced, hence fledging success was unusually poor. For example, more than twice as many clutches were laid in 1983 as in 1978, yet the total number of young fledged per pair was the same.

The range of variation in breeding success was also especially large in 1983. The most successful pair laid 29 eggs in 7 clutches and fledged 20 young. The least successful pair laid 24 eggs in 8 clutches and fledged none! This pair had bred successfully in the previous year.

The Breeding of other Species. The other species of finches on the island were not studied in detail. These species are the large ground finch, *G. magnirostris*, the sharp-beaked ground finch, *G. difficilis*, and the warbler finch, *Certhidea olivacea*. Occasional observations suggested that their breeding exhibited the same features as *conirostris*. Breeding of all of them was underway in December 1982, it ceased in July 1983, and breeding densities were high

Table 6. The number of captures in mist nest censuses conducted in the middle of March in several years. Three 12 m nets were used in the same positions for a total of 200 net-meter hours in each census (see Grant and Grant, 1980a, for further details).

	July					
	1973	1978	1980	1981	1982	1983
<i>Geospiza magnirostris</i>	15	3	0	3	4	10
<i>Geospiza conirostris</i>	22	0	2	7	2	10
<i>Geospiza difficilis</i>	63	2	4	4	5	14
<i>Certhidea olivacea</i>	3	0	4	0	0	0
<i>Nesomimus parvulus</i>	2	4	2	4	1	10
<i>Zenaida galapagoensis</i>	17	7	2	1	11	10
TOTALS	122	16	14	19	23	54

but reproductive success per attempt was relatively low.

A standard mist-netting census provides an indication of relative population sizes in the study area (Table 6). Captures of finches were higher in 1983 than in any of the previous years of the study except for 1973: 1973 was the year following the last major El Nino event. Proportions of the species are not markedly different in 1983 from previous years. For example, proportions of *magnirostris*, *conirostris*, and *difficilis* did not differ between 1982 and 1983 ($\chi^2 = 3.14$, $P > 0.05$). In view of the known increase in density of *conirostris* this argues for a similar increase in the density of all species. The special case of mockingbirds is dealt with in detail by R.L. Curry (this volume) and in the Discussion.

Immigration. Three individuals of the medium ground finch, *G. fortis*, were captured in mist nets in July, banded and released. Another two, distinguished by the color of their beaks, were also observed. All five individuals were in immature plumage.

These five individuals were almost certainly immigrants as the species has never been observed to breed on the island. Immatures have been observed on the island previously, but never in such numbers. Two were seen in July 1980 and one was captured and banded in July 1982 (but never re-sighted). One was collected by R.I. Bowman in 1973 (Yang and Patton, 1981).

A high incidence of immigration was apparent among land birds other than Darwin's Finches (Appendix). Most species had not been recorded before 1983, and only two other species, the Rough-winged Swallow (*Stelgidopteryx ruficollis*) and the Purple Martin (*Progne subis*), had been recorded in the years 1978-82 but were not seen in 1983. The most outstanding immigrants, however, were not land birds. Cattle Egrets (*Bubulcus ibis*) were seen for the first time on the island at the end of December 1982. A minimum of 120 were observed in July 1983.

DISCUSSION

The El Niño event of 1982-83 produced heavy rains on I. Genovesa for eight months. This caused a prolongation of the season of primary production for at least that length, and for longer in the case of *Croton scouleri*. Breeding densities of finches were unusually high, owing to the favourable conditions for recruitment of young birds in marginal habitat. The breeding season lasted for about as long as the extended wet season. The two unexpected features of the breeding of *G. conirostris* were the relatively low breeding success, and the termination

of the breeding season for most pairs before the rains had ceased.

The low reproductive success can be attributed largely to two factors: heavy rains and mockingbird predation. It appeared that heavy rain for several hours on successive days caused birds to desert eggs or young. In addition, rain combined with strong winds, caused breakages in the nesting trees, nest destruction itself and hence, desertion, in at least four cases. Mockingbird predation was exceptionally frequent. Part of the reason for this was the disruption of the social structure of the mockingbird population by a pox-like condition, which led to a high incidence of itinerant immatures (Curry, this volume). Either singly or in groups the immatures were often observed in the vicinity of, or actually at, finch nests. It was these wandering birds that were responsible for the high capture rate of mockingbirds (Table 6).

Early termination of breeding before the rains had ceased has not been observed in previous years. It is surprising because at this time (late June - early July) there was an abundance of seeds on plants especially *Croton scouleri*, known to be consumed by *conirostris* nestlings. Crop samples taken from *G. conirostris* nestlings in 1978 showed that caterpillars were the most frequent item followed by *Croton* seeds and then spiders (Grant and Grant, 1980a).

Our explanation for the early cessation of breeding is that the supply of arthropods had become too rare. In late June and early July arthropods were counted on 100 leaves and associated stems and flowers on each of 10 plants, spaced 10 m apart, of the 11 most common species in the study area. Results were then compared with those obtained by identical sampling in 1978. The 1983 arthropod numbers on each plant species were 1-2 percent of the maximum numbers available in 1978, and about the

same as those present when breeding of finches ceased in 1978.

This raises the question of why the density of caterpillars had fallen so low when leaves and shoots of many plants, especially *Cordia lutea*, *Croton scouleri*, and *Ipomoea habeliana*, were still growing. Possible answers are that the parasitoid numbers had increased greatly and were controlling caterpillar numbers at low levels - parasitized caterpillars were found - and that the plants had responded to extensive defoliation by the production of chemical defenses harmful to caterpillars.

To what extent was the breeding of finches on Genovesa typical of Darwin's Finches in the archipelago? Extended breeding was almost certainly the rule. On I. Daphne, the first egg was laid at the end of November 1982 and the last fledging took place in the first few days of September 1983 (H.L. Gibbs, pers. comm.). Thus the breeding season spanned 9 months on this island. Elsewhere in the archipelago, casual observations suggest that finches were breeding everywhere in late November and early December 1982; these observations were made on islands as far apart as Wolf (Köster and Köster, 1983), Santiago, Isabela and Española (M. Jones, pers. comm.) and Santa Cruz (D. Day, pers. comm.). Breeding ceased mainly in July 1983 although some may have continued for longer at medium altitudes on the high islands. No breeding activity was observed on our brief visits to Bartolomé on August 18, Isabela (Tagus Cove) and Fernandina on August 19, Seymour on August 20, Española on August 21 and Santa Cruz (the vicinity of the Charles Darwin Research Station) on August 18-22.

Breeding was much more successful on Daphne than on Genovesa, probably because of the absence of nest predation: There are no resident mockingbirds on Daphne. Several pairs of both *G. fortis* and *G. scandens* on Daphne successfully raised 7 broods. The

maximum recorded previously was five in 1978 (Boag and Grant, 1984).

Breeding continued for longer on Daphne than on Genovesa, with many nests being started after the rains had ceased in mid-July. The reason for this appears to be the supply of caterpillars; we saw many in early August. But it is not obvious why the caterpillar supply on the two islands should be different. Since the islands differ floristically (Abbott et al., 1977; Grant and Grant, 1980a; Boag and Grant, 1984), an answer to that question resides in the autecology of the insect and plant species concerned.

The outstanding feature of the Daphne populations was the successful breeding of birds of both species born in the early part of the breeding season. The youngest was a female of *G. fortis* who laid her first egg when 81 days old and successfully fledged two offspring from a clutch of four eggs (H.L. Gibbs, pers. comm.). The rapid attainment of reproductive maturity was also suspected to occur in the *G. conirostris* population on Genovesa, but it was not established with birds of known age.

We conclude that events on Genovesa in 1982-1983 were characteristic of the events in the archipelago as a whole, perhaps more so than events on Daphne because like most other islands, Genovesa has nest predators. The short-term ecological consequences of the El Niño were easy to see. Possible micro-evolutionary consequences can only be determined by detailed analyses of quantitative data (cf. Boag and Grant, 1981) and these are being undertaken now.

Finally, how unusual were the environmental conditions associated with the El Niño event of 1982-1983? The question is impossible to answer directly, as detailed ecological studies only began in 1973

(Grant et al., 1975; Abbott et al., 1977). Therefore we have to use the rainfall records to provide an indirect answer. These records suggest the possibility that conditions experienced by the terrestrial flora and fauna in 1982-83 were the most extreme (wettest) this century.

First, rainfall records at Ancón on the coastal mainland of Ecuador show that 1939 was the wettest year between 1925 and 1980; it was probably the wettest year since 1900 (Grant, 1984). Since annual rainfall at Ancón is positively correlated with annual rainfall on the Galápagos (Grant, 1984), 1939 was probably the wettest year on the Galápagos too. It was thought to be the wettest year between 1935 and 1965 by Alf Kastdalen, a long time resident of I. Santa Cruz (Kastdalen, 1982). A creek near his house flowed with water 14 times in 1939 (Kastdalen, 1982), but flowed 40 times in 1982-83! Second, rainfall recorded at Puerto Baquerizo Moreno on I. San Cristóbal during the recent El Niño event was nearly three times greater than in any year since 1950 when records were first taken. From November 1982 until July 1983 a total of 3648 mm fell; the previous maximum in the same months was 1399 mm in 1952-53. The margin by which recent rainfall exceeded recorded rainfall in the preceding 32 years suggests that 1982-83 may have been wetter than 1939, and hence the wettest year this century.

Curiously, biologists were present on the Galápagos in each of the three wettest years preceding the recent El Niño event: William Beebe in 1925, David Lack in 1939 and Robert Bowman in 1953. Nothing they wrote hints at such extreme conditions as those prevailing in 1983. Bowman (1961, pp. 9-10) mentioned the El Niño event of 1953, but only described the climate in a "normal" year. Lack (1947) did not even mention the event of 1939. Rain began to fall in late December 1938 and ended in late February 1939. There was no rain on the coast of

Santa Cruz between February 20 and April 1 when Lack departed (Lack, 1950). The unusually heavy rains that fell in 1939 (Kastdalen, 1982) were therefore either restricted to the first eight weeks, or else resumed in April or May after a hiatus of at least five weeks. A temporary cessation is quite common (Grant and Boag, 1980; see also Figs. 1 and 3). Beebe (1924, 1926) visited the island in 1923 and 1925, and was thus able to compare their appearance in years of different rainfall. The log of the vessel *Arcturus* makes frequent reference to rain falling in April 1925. For example, an entry on April 8 reads: "Rain in the afternoon and showers in the evening. Nothing like this three [actually two!] years ago." (Beebe, 1926; p. 398). Clearly, extensive rains were experienced in the Galápagos in 1925, for a pond half a mile in length was seen on I. Española. But from other entries in the log it is also clear that conditions were not as wet as in 1983. In April 1925 masked boobies had chicks on I. Española, and on I. Genovesa the breeding of frigate birds, boobies, gulls, and noddy terns was observed. In contrast, by the month of April in 1983 all those species except frigate birds had abandoned breeding on those islands and elsewhere (R.L. Curry and M. Jones, pers. comm.).

Oceanographic conditions off the coast of Peru in 1982-83 have been described as the most extreme of the century (Cane, 1983; Kerr, 1983). We shall never be able to prove it, but it seems likely that rainfall conditions on the Galápagos were also the most extreme of the century.

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Appendix. Non-resident land birds, excluding herons, recorded on Isla Genovesa in 1983 by T. de Vries (pers. comm.), R.L. Curry (pers. comm.) and the authors. Species seen in a previous year, 1978-82, are shown by an asterisk,

Scientific Name	English Name	Minimum Number
* <u>Neocrex erythrops</u>	Paint-billed Crane	1
* <u>Coccyzus melacorhynchus</u>	Dark-billed Cuckoo	1
<u>Crotophaga ani</u>	Smooth-billed Ani	1
<u>Chordeiles minor</u>	Common Nighthawk	1
* <u>Myiarchus magnirostris</u>	Large-billed Flycatcher	1
<u>Tyrannus tyrannus</u>	Eastern Kingbird	1
<u>Riparia riparia</u>	Bank Swallow	1
<u>Hirundo rustica</u>	Barn Swallow	3
<u>Pheucticus ludovicianus</u>	Rose-breasted Grosbeak	2
* <u>Dolichonyx oryzivorus</u>	. Bobolink	1

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BREEDING AND SURVIVAL OF GALAPAGOS
MOCKINGBIRDS DURING EL NIÑO

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Summary

Mockingbirds began breeding on Genovesa in December 1982 following rain that first fell in November. Breeding occurred until July 1983, with a short break in late February and early March. Some females initiated as many as six clutches. Clutches were somewhat larger on average than in previous years. However, hatching success was unusually low. Fledgling success was normal. The net result was a typical number of fledglings per nest, but repeated breeding yielded a higher overall breeding success per female than in previous years. Most nest failures were attributable to heavy rainfall which killed eggs and newly hatched chicks. Some losses were due to predation by short-eared owls and to parental abandonment.

Population density on Genovesa was unusually low at the beginning of the breeding season. This may have been the result of heavy adult mortality caused by a pox-like disease that continued to appear in the population throughout the breeding season. In areas where disease-related mortality was high, group structure broke down. The incidence of helping at the nest was low, as many subordinate birds bred in

new territories instead of staying on the territories of the dominant birds and helping to raise their offspring.

Elsewhere in the archipelago the symptoms of a pox-like disease were observed on many islands; and population sizes did not increase greatly despite extensive breeding. For example, on the islet of Champion the breeding season apparently spanned eight months but the population size remained approximately stable at 45 birds.

Resumen

Los cucubes empezaron a reproducirse en Genovesa en Diciembre de 1982 después de las primeras lluvias que cayeron en noviembre. Hubo reproducción hasta julio de 1983, con una pequeña interrupción a finales de febrero y comienzos de marzo. Algunas hembras iniciaron hasta seis nidadas. El número de huevos por nido fue algo mayor en promedio que en los años anteriores. Sin embargo, el éxito de eclosión fue extremadamente bajo. El éxito en la salida del nido por parte de los juveniles fue normal. El resultado neto fue un número típico de juveniles por nido, pero la reproducción repetida produjo un éxito mayor por hembra que en los años anteriores. La mayor parte de fracasos de anidación son atribuibles a las lluvias que mataron a los huevos y a los pollitos recién eclosionados. Algunas pérdidas se debieron a predación por parte de lechuzas y a abandono del nido por parte de los padres.

La densidad poblacional en Genovesa fue extremadamente baja a comienzos de la estación reproductiva. Esto pudo deberse a una alta mortalidad de adultos causada por una enfermedad ("pox-like") presente en la población durante toda la estación reproductiva.

En áreas en donde la mortalidad relacionada con la enfermedad fue alta, la estructura del grupo se alteró. La incidencia de ayuda en la anidación fue baja, ya que muchas aves subordinadas se aparearon en nuevos territorios en vez de quedarse en los territorios de aves dominantes y de ayudarles a éstas a criar su prole.

En otras partes del archipiélago los síntomas de la enfermedad se observaron en muchas islas, y los tamaños poblacionales no se incrementaron significativamente a pesar de la reproducción extensiva. Por ejemplo en el islote Champion, la estación reproductiva aparentemente duró ocho meses, pero el tamaño de la población se mantuvo relativamente estable con 45 aves.

INTRODUCTION

In this paper, I will describe the effects of the 1982-83 El Niño on the breeding biology and social organization of Galápagos mockingbirds (*Nesomimus spp.*). I will concentrate primarily on results from Isla Genovesa, where I have studied mockingbirds (*N. parvulus bauri*) since 1981 following earlier work by Peter Grant and colleagues from 1978 through 1980. I will supplement this information with results from Champion, where we have monitored the small mockingbird population (*N. trifasciatus*) since 1980, and with casual observations made on other islands.

Gifford (1919) was the first naturalist to describe the general aspects of mockingbird breeding in the Galápagos. He made observations on several islands during the California Academy of Sciences Expedition of 1905-06, and found that mockingbird nest-

ing occurred during the wet/warm season, which usually falls between January and May. This pattern of breeding is typical of small Galápagos landbirds (see Lack, 1950; Grant & Boag, 1980). Of later observers, only Venables (19140) happened to study mockingbird nesting during an El Niño year; his study during 1939 took place at the start of what was probably the most extreme El Niño in this century prior to 1982-83 (Grant, 1984; Grant & Grant, this volume). Despite this fact, nesting of *N. melanotis* on San Cristóbal that year began in January and ended by late February, matching the chronological pattern of a "normal" year. More recent studies of *N. macdonaldi* on Española (Hatch, 1966; Groves, 1974) and of *N. parvulus parvulus* on Santa Cruz (Vargas, 1980) have confirmed that mockingbird nesting usually does not begin until after the first heavy rains, and it ends before or soon after the rains cease; three clutches at most are produced under "normal" conditions.

Mockingbird breeding and feeding on Genovesa was first studied in 1978. During this roughly normal year, the Grants discovered that helpers were feeding young at many nests (Grant & Grant, 1979). The Genovesa mockingbirds, therefore, are cooperative breeders. Because cooperative breeding is currently an important topic in evolutionary biology, (see reviews by Brown, 1978; Emlen, 1978) the Genovesa study has continued. Mockingbirds on Genovesa live in groups that defend collective territories, and helping at the nest is a regular feature of their social organization. The basic features of this system have been described by Kinnaird & Grant (1982). In my own work, I am attempting to answer questions about the evolution and ecology of cooperative breeding in Galápagos mockingbirds as a group. Study of *N. trifasciatus* on Champion was initiated in 1980 to see if cooperative breeding was common to other mockingbirds in Galápagos and to determine what aspects of social behavior differ among the islands (see N. Grant,

1983). The long-term study on Genovesa, and comparisons from less intensive study of the Champion mockingbirds, form the basis of my research.

The results I report here are particularly interesting for two reasons. First, we can determine the effects of El Niño on general aspects of mockingbird breeding biology by comparing 1982-83 results with those from five preceding years. Secondly, we can determine the effects of the heavy and prolonged rainfall of 1982-83 on the social behavior of the mockingbirds. Without the years of study leading up to the recent El Niño, we would not be able to assess adequately the full impact of this amazing climatic phenomenon on the mockingbirds of Galápagos.

BREEDING BIOLOGY

Mockingbirds on Genovesa probably began breeding in December 1982, following rain that began in November (see Grant & Grant, this volume. When I initiated fieldwork on 31 December, there were some recently fledged young in the study area, but none that had been out of the nest for more than a few days. Given that the nestling period averages about 13 days, incubation 12 days, and laying 4 to 5 days (Grant & Grant, 1979) it is likely that the nests that produced these young were initiated on or about December 1. Many territories at this time did not have fledged young; it is likely that many of the early nests were destroyed by heavy rain, especially during an archipelago-wide storm on 15 December. Pairs with and without fledglings immediately initiated second clutches, with some females overlapping the start of laying with the end of the nestling period of their preceding nest.

The distribution of nest starts and rainfall for the past four seasons is shown in Fig. 1. Some

NESTING PHENOLOGY AND RAINFALL

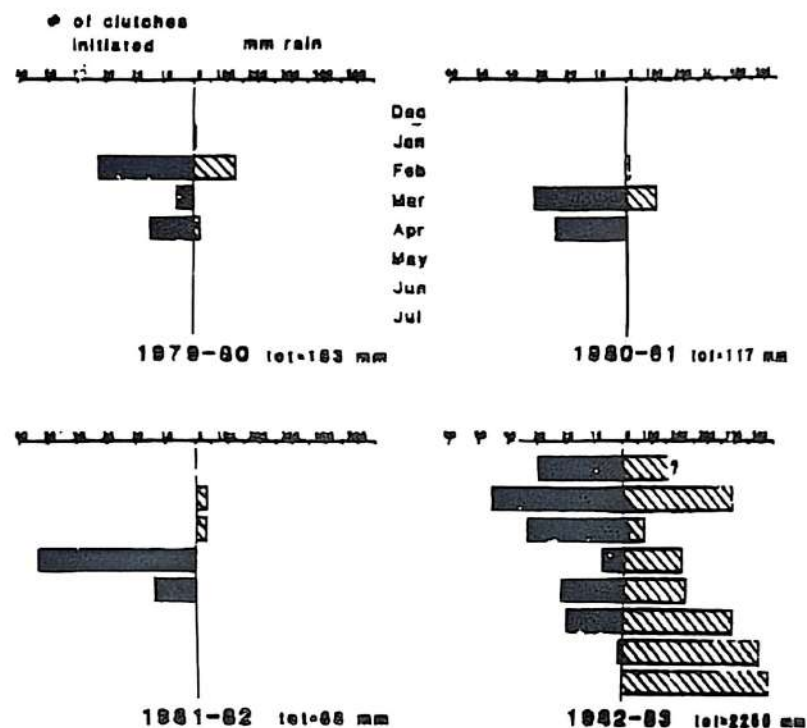


Figure 1. Clutch initiation in relation to rainfall on Genovesa during the years 1980-1983.

female mockingbirds initiated as many as six clutches during the extended 1982-83 season (Table 1). Breeding was nearly continuous between December and July. The only break during the season occurred in late February and early March, following a period of about two weeks with only trace amounts of rain in February. Though food supplies were not quantified throughout the season, it appeared that insect densities dropped quickly during this dry spell, particularly because it coincided with clear skies, intense

Table 1. Number of females attempting to breed 1-6 times on Genovesa in 1980-83.

N = total number of females breeding in the study area.

	N	Number of Nests Initiated					
		1	2	3	4	5	6
1980	74	59	14	1			
1981	60	55	5				
1982	54	41	13				
1983	58	22	7	10	9	6	4

Table 2. Mean ($\bar{X}$) clutch size on Genovesa, with one standard error (SE), for the years 1980-83.

N = Sample size.

	Clutch Size		
	N	$\bar{X}$	SE
1980	46	3.65	0.64
1981	62	3.87	0.59
1982	59	3.81	0.57
1983	113	4.36	0.64

solar radiation, and high temperatures. During this period, nestlings starved, and the mockingbirds delayed starting their next nests. Mockingbird nest-

Table 3. Percentage of 1983 nests on Genovesa in which some, all, or no eggs hatched.
N = sample size of nests.

	N	Eggs Hatched		
		None	Some	All
1980	51	9.8	21.6	68.6
1981	65	18.5	44.6	36.9
1982	63	19.0	39.7	41.3
1983	120	35.0	47.5	17.5

Table 4. Mean fledglings/female/season (X) for the years 1980-1983 on Genovesa.
N = sample size, SE = standard error.

	N	Fledglings/Female		
		X	SE	Range
1980	84	2.08	2.18	0 - 9
1981	60	1.42	1.46	0 - 5
1982	54	1.28	1.31	0 - 4
1983	58*	2.55	2.60	0 - 3

*Females that may have bred in December 1982, but who died shortly after study resumed, are not included in the 1983 totals.

ing resumed as soon as the rains returned in later march. The last mockingbird nest on Genovesa was initiated on 22 June, and all breeding had ceased when the final chick in this nest died on 22 July. The reason why breeding did not continue past this date is unclear, since more rain fell during the first three weeks of July than in any other equivalent period during the year. It is probable that the vegetation responded in a different way to this late rain than it had earlier, hence affecting insect abundance and mockingbird breeding (see Grant & Grant, this volume). Density-dependent effects may also have begun to predominate in the mockingbird population (see below).

Table 5. Percentage of nests failing or succeeding following hatch of at least one egg on Genovesa.

N = sample size of nests.

	N	Failed	Successful
		(0 Fledglings)	(≥ 1 Fledglings)
1980	46	41.3	58.7
1981	53	37.7	62.3
1982	51	39.2	60.8
1983	79	46.8	53.2

Success of individual nesting attempts by mockingbirds on Genovesa was not greatly affected by the El Niño conditions. Clutch size was higher than in previous years (Table 2), particularly for clutches initiated early in the season. Mockingbirds appeared

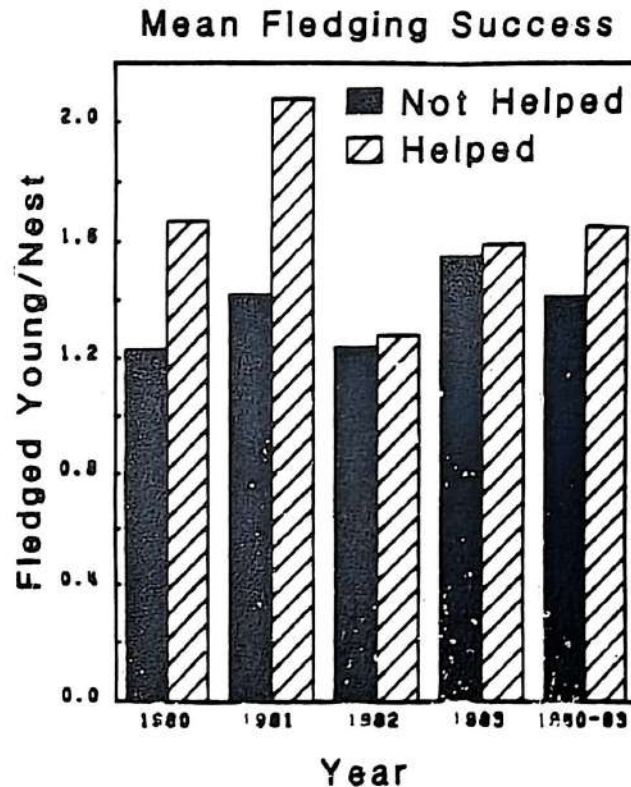


Figure 2. Mean annual fledging success at nests with and without helpers, Isla Genovesa.

to adjust their clutch size to exceptional rainfall to a greater degree than do Darwin's finches (Grant & Grant, this volume).

Increased clutch size was, however, largely offset by decreased hatching success. The proportions of nests in which all, some, or none of the eggs hatched differ significantly among the years 1980 through 1983 (Table 3). Decreased hatching success was followed by a normal fledgling of hatched

young (Table 4). The proportion of nests fledgling at least 1 young following successful hatch did not differ significantly among years (Table 5), although it was lowest in 1983. The final result was that the mean number of fledged young per nesting attempt was comparable with previous years (Fig. 2). This contrasts with the decreased number of fledglings per nest in Darwin's finches. Most mockingbird nest failures were attributable to heavy rainfall, especially when eggs or newly hatched chicks were chilled during prolonged showers. Other losses were due to predation by short-eared owls or parental abandonment. Mockingbirds did not appear to suffer heavily from intraspecific predation (infanticide), though I did observe wandering immature mockingbirds inspecting nests. These birds were usually chased away immediately by the resident birds, and probably seldom had opportunities to break or steal eggs, or eat nestlings. The absence of this mortality factor in the mockingbirds appears to explain the difference in success per nest between mockingbirds and Darwin's finches on Genovesa (see Grant & Grant, this volume).

Because most females nested repeatedly throughout the season and had good reproductive success per nest, the average success per female was significantly higher for the 1982-83 season than in previous years (Table 4). This success had direct effect on the size of territorial groups and on the density of the mockingbird population as a whole. These results are described in the following section.

DEMOGRAPHY

Early in the season, population density in the study area on Genovesa was as low or lower than at any previous point in this study. Some mortality is expected during any dry season; juvenile survival is

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usually low but adult losses are not great, averaging about 20 percent from year to year. As soon as I arrived on Genovesa in December, it became apparent that many adults in the study area had disappeared while recruitment of 1982 juveniles had been typically low. About 100 adult mockingbirds were present in 24 groups. I attribute the bulk of the adult mortality to a pox-like disease that was affecting many mockingbirds in December. I observed birds with lesions symptomatic of this infection throughout the season, and many affected birds subsequently disappeared and are presumed to have died. Avian pox virus has been observed on Santa Cruz and another islands, especially those inhabited by humans and their domestic animals, since at least 1905, when affected birds were common on San Cristóbal (Gifford, 1919). Lesions are found especially about the bill, eyes, and mouth, but many other parts of the body can also be affected (e.g. the skin on the wings and chest and the feet).

Some territorial mockingbird groups on Genovesa were not affected by disease, and the structure of those groups was comparable to previous years (see below). Losses due to disease were quickly offset by recruitment of fledged juveniles as the season progressed, despite the fact that both adults and young mockingbirds with pox-like symptoms continued to disappear. By July, approximately 400 marked mockingbirds were resident in the study area, compared to less than 200 at the end of the previous breeding season. The largest group at this time contained 15 birds, with 9 of them birds-of-the-year on their natal territory. Group size normally ranges between 2 and 10 birds on Genovesa (Curry, in prep).

SOCIAL BEHAVIOR

In territories where few birds died due to disease, group integrity was maintained throughout the season. Despite steady increase in group size as successful nesting continued, dominance hierarchies among the adults were sustained; no groups had fissioned by the end of the season.

As in the preceding years many subordinate males were able to attract mates into their groups. During El Niño, the nesting of these subordinate pairs was particularly successful - their breeding efforts were not disrupted by more dominant birds as they are during more typical years (Curry in prep). Nest of subordinate pairs seldom have helpers, so the increased breeding of subordinates added to the proportion of nests without helpers. In addition, no subordinate males helped and bred simultaneously, though this did not occur in other years (Curry, in prep). Furthermore, the number of 1- and 2-year old males that most frequently act as helpers (Kinnaird and Grant, 1982) was reduced by disease-related mortality. The combination of these factors resulted in a large, though not statistically significant, decrease in the overall incidence of helping (Table 6). Note that the proportion of nests with helpers in 1983 (31.9%) was still larger than the 28% reported by the Grants for 1978, but the real proportion of nests with helpers in that year was probably higher (Grant & Grant, 1979).

Those birds that did help during El Niño had little effect on breeding success; the average number of fledglings was similar for nests with and without helpers (Fig. 2). Though I have not yet analyzed

Table 6. Proportion of nests with helpers on Genovesa, 1980-83.

	Number of Nests		Percent
	Without Helpers	With Helpers	With Helpers
1980	26	18	40.9
1981	26	24	48.0
1982	29	25	46.3
1983	62	29	31.9

data on nestling diets and feeding rates by the different participants, suitable food appeared to be superabundant throughout most of the season except in March (see above). Since reproduction was limited by losses during hatching (see above), helpers were unable to increase output of fledglings. Some juveniles helped at their parents' nests, but had no more effect on success than did adult helpers.

In areas where disease-related mortality was high, group structure broke down. This occurred especially, but not always when the highest ranking male was among those that died. Some adults and many juveniles, both from outside the study area and from neighboring territories, collected in these largely vacant areas. The adults eventually settled and nested, but the juveniles wandered singly or in loose bands. Territory boundaries were not reestablished, and the young birds, unrestricted by normal dominance interactions and territories, plundered many finch nests. Group structure had still not emerged by the end of the breeding season, but territory boundaries

and group affiliations were apparent among the same birds by December 1983 (pers. observ.).

OTHER ISLANDS

I do not have any data to indicate when breeding began on Champion. No fledglings were obvious on the islet in mid-January (G. Robinson, pers. comm.), though it is likely that the mockingbirds were nesting at that time. I made very brief visits to Champion in late March and late May. In March, there were fledglings as well as additional nests in progress in most of the islet's 10 territories. Vegetation here was very thick and the vines and herbs, especially *Mentzelia*, made walking nearly impossible. The mockingbirds, perhaps to avoid the clinging leaves of this ground layer, spent most of their time in the large *Opuntia* trees, and nestlings were being fed newly-molted locusts (*Sphignonotus tetraneis*). One nest with chicks was being attended by at least four adults; *N. trifasciatus* is certainly a cooperatively breeding species.

Breeding on Champion was still underway in May. I estimate that the nests then present were either third or fourth clutches. Several nests contained the combined clutches of two females, with both incubating; communal nesting of this kind occurs rarely but regularly on Genovesa as well (Curry, in prep). Though the data are not complete enough for detailed analysis, it appears that success per nest was low on Champion - several territories that had nests with eggs in March had no additional fledglings in May. Though there may have been other factors, some losses were probably due to disease. Mockingbirds with pox-like symptoms similar to those on Genovesa were present during both of my visits.

Subsequent work on Champion has revealed that breeding on the islet continued into at least late August, since we found mockingbirds in juvenile plumage in December 1983. The net effect of El Niño on Champion was neutral - the size of the relict mockingbird population on this islet remains stable at about 45 birds. The majority of the population now consists of young birds, as juveniles have replaced older birds that died from disease.

Fragmentary breeding data are available from only two other islands. There were no mockingbird fledglings in the vicinity of CDRS on Santa Cruz in late December 1982, but there was much green vegetation. Early nests here were probably rained out, especially by the intense storm on 15 December. Breeding near CDRS was still in progress in June 1983. On Española, there were still some active nests in late August (M. Iturralde, pers. comm.).

The pox-like disease was apparent on most islands. The outbreak near Puerto Ayora on Santa Cruz was particularly severe early in the season; there were far fewer affected birds by CDRS by June (pers. observ.). Mockingbirds with identical symptoms were also present on Santa Fe (A. Laurie, pers. comm.), and Española (P.R. Grant, pers. comm.). The disease thought to be avian pox is common during most breeding seasons on Santa Cruz, where 28% of chicks were affected in 1980 (Vargas, 1980), but previously affected birds had been seen only rarely on the arid, uninhabited islands.

The demographic shift towards young birds produced by the combination of repeated nesting and adult mortality seems to have taken place on most islands. By early June, the majority of mockingbirds present on Fernandina, Isabela, and Santa Cruz were juveniles (pers. observ), as on Genovesa and Champion.

DISCUSSION

The principal effect of the El Niño on Galápagos mockingbirds was the prolongation of conditions favorable for breeding. In a typical year, the wet, season is brief, beginning in January and often over by late February. In these years, few mockingbird pairs are able to raise more than one brood. Fledgling success of additional clutches is reduced by starvation of nestlings, since parents are unable to find adequate food as the vegetation quickly dries out. During El Niño, heavy rain resulted in an advance in the onset of nesting by about two months. Nearly continuous rainfall in the months that followed prevented the vegetation from drying and caused it to grow profusely. Without the normal decline in breeding conditions, the mockingbirds nested continuously. Breeding ended only when most females had attempted several clutches, some as many as six. Though rain continued to fall into July, it appears likely that insect abundance had begun to decline by June, coinciding with the last few nest starts on Genovesa. By the time the last nest terminated - its nestlings apparently starved - the breeding season for the mockingbirds had lasted at least eight months. The El Niño, then, had a largely favorable effect on Galápagos mockingbirds.

The advantageous continuation of breeding conditions, though, was offset in two important ways. One of these, decreased hatching success, is a direct result of weather conditions - severe storms with torrential rainfall and high winds - that destroyed nests outright or forced females to leave their nests. Highest losses appeared to result from storms lasting several hours; incubating females were eventually forced to leave their nest to forage, and

their eggs became chilled when they did so. Reduced hatching success offset the increase in number of hatchlings that would have been expected from the substantial increase in average clutch size.

The other factor that affected the Genovesa mockingbird population during El Niño was disease related mortality. It is not clear at this time if the incidence of pox-like disease on Genovesa during 1982-83 was directly associated with the El Niño. Avian pox can be transmitted by mosquitoes, and mosquito density on Genovesa was certainly much higher than normal during El Niño (pers. observ.). Thus it is possible that the increased density of vectors led to an outbreak of a disease that previously had little effect on mockingbirds. This hypothesis, however, is difficult to reconcile with the observation that other landbird species on Genovesa, which elsewhere are commonly victims of avian pox, were hardly affected at all by the disease that afflicted the mockingbirds on Genovesa. Perhaps the strain of pox virus that was prevalent on Genovesa was specific to the mockingbirds. Alternatively, mockingbird behavior, especially fighting, might contribute to more rapid disease transmission than in the less social finches. We do not know its identity. Its effect was clear, however. Many adult mockingbirds in the study area, and across the entire island, were infected during the breeding season, and many of them disappeared, or were at least so sick as to be unable to raise their young. If so many adult mockingbirds had not been affected by this disease and had continued to breed, the net effect of the El Niño would have been even more favorable, and the resulting density of mockingbirds on Genovesa would have been greatly enhanced.

Aside from repeated nesting, there were few other important breeding responses by the mockingbirds. It appears that by increasing clutch size,

mockingbird females were trying to take advantage of the unusually favorable conditions in order to raise more young than usual. Most, however, were prevented from doing so by the severity of the weather. Another indication that the mockingbirds were doing all they could to maximize reproductive output was the initiation of new clutches before previous broods had fledged. This was particularly noticeable early in the season, when mockingbird density was still low and vegetative growth was increasing rapidly. In general, though, El Niño simply permitted the mockingbirds to keep nesting, rather than causing them to breed in a qualitatively different way.

Similarly, mockingbird social behavior on Genovesa was not greatly affected by the El Niño conditions. The two most important effects were the reduction in the number of nests with helpers and the fact that nests with helpers had no better fledglings success than those without helpers. In some years, helping appears to be the only way some young mockingbirds can achieve any degree of reproductive success, even if indirect. In the El Niño year, however, helping was a less favorable option, and those birds that chose to help rather than breed did not appear to gain as much as they would have done had they bred. This combined with the fact that many young birds, which in a normal year probably would have helped, chose instead to breed, and did so successfully, suggests that when conditions are extremely favorable for breeding, the cost-benefit balance between helping and breeding shifts toward breeding. This aspect of mockingbird biology on Genovesa will be dealt with in detail in forthcoming papers.

The combination of repeated successful breeding, maintenance of the social system, and disease-related mortality produced, by the end of the season, two different results. In those groups that happened to be spared the effects of disease, group integrity was

maintained and the size of these groups increased markedly due to recruitment of juveniles. In other parts of the study area, there were no structured groups by the end of the season: either whole groups had succumbed to disease, or their dominant birds had died and the groups disbanded. In these areas, a large number of juveniles, many produced in adjacent intact groups, settled but failed to establish groups. With adults to enforce dominance relationships, interactions among birds in these areas continued to be chaotic, though some older immature birds had begun to establish site dependent dominance by late in the season. Similarly, without adults to chase off intruding juveniles, these areas experienced a steady stream of wandering mockingbirds. One result of this situation was obvious: finches attempting to nest in these areas suffered very high nest predation by mockingbirds. Without the matrix of adult territories to limit the movements and density of juvenile mockingbirds, they were able to effectively scour large areas of all finch nests (see Grant & Grant, this volume).

It is impossible at this point to determine the extent to which the effects of El Niño on the Genovesa mockingbirds were typical of mockingbirds on other islands. The meagre data available suggest that pox-like disease was prevalent throughout the archipelago; this supports the idea that the prevalence of the disease was affected directly or indirectly by the unusually heavy rainfall. By June, juvenile mockingbirds appeared to outnumber adults on many islands, indicating that breeding was successful throughout the archipelago. None of the data from Champion differ substantially from those collected on Genovesa, though for unknown reasons, mockingbird breeding ended earlier on Genovesa than at some other islands, including Champion.

In 1984, I will conduct a comparative study of all four species of *Nesomimus*. Though it will not be

possible to fully assess the effects of El Niño in this way, I will at least determine whether or not the biology of the different mockingbirds varies substantially during the recovery period following this historic climatic phenomenon.

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STUDIES OF THE LITTLE FIRE ANT,
WASMANNIA AUROPUNCTATA, IN A NIÑO YEAR

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Summary

The little fire ant, *Wasmannia auropunctata*, continued to expand its range during El Niño year. In transition and humid zone areas of Santa Cruz I., the expansion occurred at an alarming rate, 3 times the rate estimated for the previous 6 years. Dispersal in the arid zone was considerably slower. Nonetheless, various observers concurred in their impression of a dramatic increase in densities of the little fire ant in the village of Pto. Ayora in the arid zone, as well as in the cultivated parts of the transition and humid zones.

At least one other ant species, *Tetramorium bicarinatum*, benefitted from the El Niño conditions. It was abundant on Española I., where it may have displaced the native carpenter ant, *Camponotus macilentus*, and on Santa Fe I., where it was not previously reported to occur.

Certain arthropods that are normally considered humid-zone species, notably chironomid midges and other nematocerous flies and some web-building spiders, invaded the arid zone during El Niño year. Other typically arid-adapted species may have suffered a decline in abundance. Will these changes affect the distribution and abundance of terrestrial invertebrates in the long run? Only long term studies will provide an answer to this question. It

is quite likely that major colonization events and the consolidation of territorial conquests by opportunistic species such as *W. auropunctata* and *T. bicarinatum* occur in El Niño years. Once established, these aggressive colonists may then have a pronounced effect on other native invertebrates.

Resumen

La pequeña hormiga de fuego, *Wasmannia auropunctata*, continuó expandiendo su distribución durante el año de El Niño. En la zona de transición y la zona húmeda de la I. Santa Cruz la expansión procedió a una tasa alarmante, tres veces la tasa estimada en los 6 años anteriores. La dispersión en la zona seca fue más lenta. No obstante, varios observadores coincidieron en su impresión sobre un incremento dramático en la densidad de esta hormiga, tanto en el poblado de Pto. Ayora en la zona seca, como en los sectores agrícolas de la zona de transición y de la zona húmeda.

Por lo menos una especie más de hormiga, *Tetramorium bicarinatum*, se benefició con las condiciones de El Niño. Fue abundante en I. Española, donde posiblemente ha desplazado a la hormiga carpintera nativa, *Camponotus macilentus*, y en la I. Santa Fe, donde no se la encontró previamente.

Ciertos artrópodos que normalmente se consideran como especies de la zona húmeda, especialmente los quironómidos y otras moscas del suborden Nematocera, y ciertas arañas de tela, invadieron la zona seca durante el año El Niño. Otras especies adaptadas a la zona árida sufrieron una posible baja en abundancia. ¿Afectarán estos cambios a largo plazo la distribución y abundancia de los invertebrados terrestres de Galápagos? Solamente los estudios futuros pueden darnos la respuesta. Es probable que los eventos importantes de colonización y de consolida-

ción de territorios por especies oportunistas, tales como *W. auropunctata* y *T. bicarinatum*, ocurran en años El Niño. Una vez que se establecen, estos colonos agresivos pueden tener efectos pronunciados sobre los otros invertebrados nativos.

In 1981 and 1982 a study was begun of the introduced little fire ant, *Wasmannia auropunctata*, in the Galápagos Islands, with the aim of determining its distribution, rate of colonization and effect on native terrestrial invertebrates (Lubin 1984). Previous studies (Clark et al. 1982) provided baseline information on the distribution and abundance of this ant on Santa Cruz I. High densities of *Wasmannia* were associated with a dramatic reduction in the diversity of other species of ants and in the abundance and diversity of certain other terrestrial invertebrates (Clark et al. 1982; Lubin 1984).

El Niño phenomenon provided an opportunity to track the advance of *Wasmannia* during a prolonged period of hot, humid conditions, precisely those conditions which might be expected to favor its spread. Changes in presence and abundance of other species of ants and of certain other invertebrates were also noted, for the most part in a purely qualitative way. Some species became so abundant during El Niño year, in particular herbivorous insects (acridid grasshoppers, larvae of Lepidoptera, nematoceros flies) that even the casual observer could not help but comment on the population explosions.

Methods

For the most part, the methods used were similar to those adopted in the 1981-82 study (Lubin 1982). Collections of ants were made on various islands as a part of a detailed study of the Galápagos ant fauna

(in prep.). The distribution of *Wasmannia* was mapped at sites not visited in 1981-82: Floreana I., Punta Albemarle and Caleta San Pedro on Isabela I., and the south-eastern edge of its distribution on San Salvador I.

I continued to monitor the movement of the 'front' of *Wasmannia* along the Pto. Ayora-Baltra Road on Santa Cruz I. In 1976, a census of ant species was made on transects oriented perpendicular to the road on the north side of Santa Cruz I. (Clark et al. 1982). The census was repeated in March 1982, with some modifications on methods, and some of the same transect lines were examined again in April 1983. The transect lines were 100 m long by 2 m wide, divided into 10 m long sections, and were located at intervals of 0.5 or 1 km along the road. Two people searched for ants in the vegetation and under rocks and logs along the length of each transect.

I repeated a similar visual census of ants along the northern boundary of the little fire ant at Guayabillos (approx. 230 m asl), on San Salvador I. Although the exact 1982 transect lines were not repeated (due to changes in the vegetation, I could not locate the previous lines), the 100 m x 2 m long transects were in the same area as the previous ones. The densities of scorpions (*Hadruroides maculata galapagoensis*) and centipedes (*Scolopendra galapageia*) were estimated from visual searches under rocks and debris in 20 quadrats, 20 m² each, 10 in a *Wasmannia*-infested area and 10 in an adjacent non-infested area.

Aerial sticky traps were placed in adjacent areas with and without *Wasmannia* at Guayabillos (10 traps in each area) and at Trágica, well within the *Wasmannia*-infested zone (at approximately 330 m elevation). Insects caught in the traps during a

24-hr period were sorted to species and counted. The results are compared with those from 1982.

All statistical tests follow Sokal and Rohlf (1969).

Results

Expansion of *W. auropunctata*

Santa Cruz I.

The little fire ant continued its advance southward into the diminishing *Wasmannia*-free zone in the center of Santa Cruz. In 1976, *Wasmannia* occurred on the north side of the island in a narrow, east-west oriented strip, between 400 and 500 m asl. The strip was approximately 2.5 km wide where it crossed the Pto. Ayora-Baltra Road which bisects the island in a more-or-less north-south orientation (Clark et al. 1982). By 1982, six years later, the ants had expanded approximately 1 km to the south along the road, reaching an elevation of about 580 m (Lubin 1984). Between March 1982 and April 1983, they continued to move southward along the road reaching an elevation of 600 m (Fig. 1). The rate of expansion during this period was approximately 0.5 km/year, almost three times that estimated for the period of 1976-1982 (0.17 km/year).

Oddly enough, the northern boundaries of *Wasmannia* on both the north and south sides of the island appear to have remained stable. On the south side of the island, the ants had not moved up into the National Park area from the agricultural lands to the south, nor had they expanded downwards (below 400 m) into the arid zone on the north slope of Santa Cruz.

In addition to the invasion of new areas, *Wasmannia* consolidates its hold on areas that were

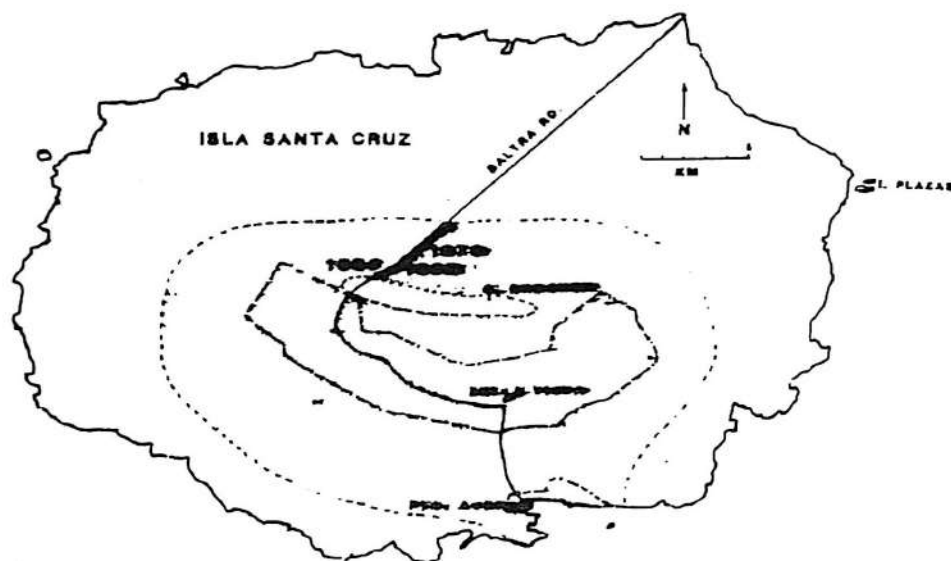


Figure 1. Map of Santa Cruz I. showing the approximate distribution of *Wasmannia* in 1983 (shaded) and the boundaries of *Wasmannia* along the Pto. Ayora-Baltra Road. Dot-and-dash lines indicated the boundaries of agricultural and urban zones (not part of the Galapagos National Park).

previously only sparsely populated by this species. In 1982, the little fire ant occurred on 5 out of 10 sections of a 100 m long transect perpendicular to the Pto. Ayora-Baltra Road at 550 m asl (2.5 km north of the boundary of the National Park with agricultural lands to the south), nine other species of ants occurred on the transect, with a total of 3-6 species per section. In 1983, *Wasmannia* was found in high population densities on all 10 sections and no other ant species were seen.

The .

San Salvador I.

The eastward expansion of *Wasmannia* in the area of the giant tortoise nesting zone at Guayabillos (nesting zone D) was considerably less dramatic than along the Pto. Ayora-Baltra Road on Santa Cruz I. Between early July of 1982 and the end of February 1983, the ants had advanced an average of 6.2 ± 1.3 m (6 measurements along a front 70 m long), giving a rate of expansion of approximately 9 m/yr. Whether the ants have spread at a faster rate on other parts of San Salvador is not known. *Wasmannia* does appear to have become firmly established on the south side of James Bay (in the area of the old salt mines) on San Salvador I., whereas in 1982 it was found only on the north side of the bay in the mangroves of Pta. Espumilla (Fig. 2).

The south-eastern edge of the distribution of *Wasmannia* on San Salvador I. in 1983 was at an elevation of approximately 240 m (Mirador, about 4 km SE of Guayabillos). Along the southern side of San Salvador, the little fire ant may extend to about 120 m (400 ft.).

Although the territorial expansion of *Wasmannia* on the Guayabillos area was relatively small, the increase in population density in some areas was alarming. In 1982, I found 0.75 ± 0.37 groups of *Wasmannia*-infested area near the edge of its distribution (groups include both nests and groups of workers with or without brood). In 10 quadrats in the same area in 1983, there were 1.75 ± 1.06 groups per m^2 , a greater than twofold increase ($t = 3.783$, $p < 0.001$). Of the 1151 potential nesting sites examined in these quadrats (rocks and fallen branches), 31.5% were occupied by ants. Nearly 25% of the groups had winged female reproductives in them.



Figure 2. Map of San Salvador I. showing the distribution of *Wasmannia* in 1983. Closed circles indicate sites at which *Wasmannia* was found in 1982 and 1983. The southern boundary of *Wasmannia* (dashed line) is approximate.

Other Islands

In 1982 *Wasmannia* was reported at Caleta San Pedro, on the southern side of Isabela I., west of Pto. Villamil (C. Márquez, pers. comm.). This new introduction was confirmed in 1983 and the ants were found to occupy a strip of about 200 m long in mangroves and beach vegetation, in an area used as camp-site by National Park wardens and scientists. The ants were probably introduced between 1980-1982.

The distribution of *Wasmannia* on Floreana I. in 1983 was restricted to an area of approximately 500 m in diameter (around the Asilo) on the north-west side of Cerro Azul at about 280 m elevation. As in other

places invaded by *Wasmannia*, few other species of ants were encountered in this zone, where as up to 7 species were found in adjacent, non-infested areas.

Wasmannia was reported from the northeast side of Santa Fe I., near the tourist landing site, in January 1984. Since I did not find *Wasmannia* at that same site in June 1983, the introduction must have been quite recent.

Studies of Other Ant Species

At Guayabillos, on the north-western side of San Salvador I., *Wasmannia* was absent or occurred only sparsely on 10 of the 50 transect sections and was found in high densities on the remaining 40. The distribution of other species of ants on the transects was clearly related to the abundance of *Wasmannia* (Table 1, Fig. 3A). Up to 5 other species of ants were found on a transect section, but the vast majority of sections on which *Wasmannia* was abundant had fewer than 3 other ant species and 35% had none (Table 1).

The 1982 data from 8 transect lines at Guayabillos were re-analyzed (Table 2, Fig. 3B) and compared with those from 1983. Although the transect lines in the two years were not the same, they were in the same area, spanning the boundary of *Wasmannia*. There were marked differences between the two years in the occurrence of certain species: (1) Fewer species overlapped with *Wasmannia* on the transect sections at the edge of its distribution in 1982 than in 1983, and 70% of the sections where the little fire ant occurred in high densities had no other species in 1982, compared with 35% in 1983. (2) Ants that appeared to be more common in 1982 than in 1983 include *Cardiocondyla* spp. and *Conomyrma albemarlensis*. The latter species, while found at other sites in the Guayabillos area, did not occur at

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Table 1. Numbers of ant species (excluding *Wasmannia*) on transect sections at Guayabillos (San Salvador I.) in 1983, in areas sparsely inhabited by *Wasmannia* (or not at all) and in areas of dense infestation of *Wasmannia*, shown as the number of transect sections occupied by 0-2 and 3-5 different species of ants (2 x 2 contingency table; G statistic used to test for significance).

	Number of Ant Species		
<i>Wasmannia</i>	0-2	3-5	Total
Sparse	4	6	10
Dense	36	4	40
Total	40	10	50
$G = 10.574, p < 0.005$			

Table 2. Numbers of ant species on transect sections at Guayabillos (San Salvador I.) in 1982 (data re-analyzed; Lubin 1984), as in Table 1.

	Number of Ant Species		
<i>Wasmannia</i>	0-2	3-5	Total
Sparse	10	11	21
Dense	59	0	59
Total	69	11	80
$G = 34.999, p < 0.005$			

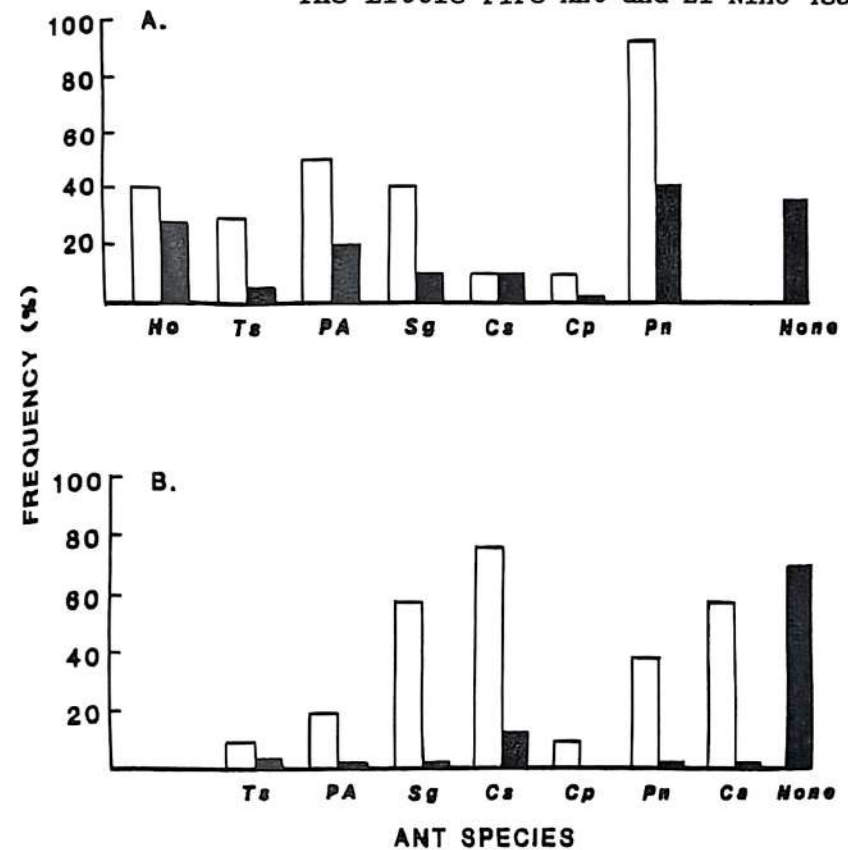


Figure 3. Frequency distribution of ant species on transect sections at Guayabillos (San Salvador I.) in areas sparsely inhabited by *Wasmannia* (or not at all) and in areas of dense infestation, shown as the percent of sections occupied by each ant species. Open bars: *Wasmannia* scarce or absent; closed bars: *Wasmannia* abundant.

A. 1983 census: *Wasmannia* scarce or absent, n = 10 transect sections; *Wasmannia* abundant, n = 40 sections.

B. 1982 census: *Wasmannia* scarce or absent, n = 21 sections; *Wasmannia* abundant, n = 59 sections.

Ca = *Conomyrma albenarlesi*, Cp = *Camponotus planus*, Cs = *Cardiocondyla* spp., Hb = *Hypoconerops beebai*, Ho = *H. opaciceps*, PA = *Pheidole* sp. A, Pv = *Paratrechina nesiotes*, Pw = *Pheidole williamsi*, Sg = *Solenopsis globularia*, Tb = *Tetramorium bicarinatum*, Ts = *T. simillimum*.

all on the 1983 transects. Other species, such as *Paratrechina nesiotis*, *Tetramorium simillimum*, *Pheidole* sp. A, and *Hypoponera opaciceps* were more common in 1983. The latter species was not collected at Guayabillos in 1982, although it was found at higher elevations in the center of the island where it sometimes overlapped with *Wasmannia*.

A similar reduction of diversity of ant species following the invasion of *Wasmannia* was observed at mirador, on the south-eastern boundary of its distribution on San Salvador I. (Table 3, Fig. 4). The overall diversity of ant species in this area was considerably higher than at Guayabillos, reflecting perhaps a greater diversity of micro-habitats (sparsely vegetated lava flows, *Psidium galapageium* woodland on rocky slopes, dense *Clerodendron molle* thickets along watercourses and areas of low grasses and annuals). As many as 8 species occurred on a single 10 m section of transect, but no more than 4 species co-occurred with *Wasmannia* in areas where the latter was found in high densities.

Table 3. Numbers of ant species on transect sections at Mirador (San Salvador I.), as in Table 1.

	Number of Ant Species			
<i>Wasmannia</i>	0-2	3-5	6-8	Total
Sparse/Absent	0	22	15	37
Dense	11	2	0	13
Total	11	24	15	50

$$G = 21,769, p < 0.005$$

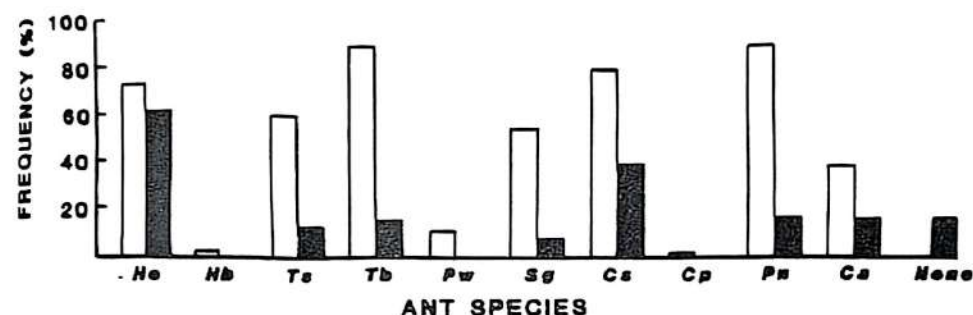


Figure 4. Frequency distribution of ant species on transect sections at Mirador (San Salvador I.) in 1983. *Wasmannia* scarce or absent, $n = 37$ sections; *Wasmannia* abundant, $n = 13$ sections. See Fig. 3 for details.

Nearly all species of ants at both sites and in both years were affected negatively by the presence of *Wasmannia*, with exception of *H. opaciceps*, and to a lesser extent *Cardiocondyla nuda* and *C. emeryi*. *Hypoponera opaciceps* was found (although rare) in areas where *Wasmannia* occurred in high densities (e.g. at Trágica on San Salvador I.). Because it is almost entirely hypogeic, or at least inside rotting logs and leaf litter, it may avoid direct interactions with *Wasmannia*. *Cardiocondyla nuda* and *C. emeryi* overlapped with the little fire ant only at the expanding front of the latter, e.g. at Guayabillos and Mirador on San Salvador I. and along the Pto. Ayora-Baltra Road on Santa Cruz I. Both species of *Cardiocondyla* are small ants with cryptic habits and might interact with *Wasmannia* only when the latter occurs in high population densities.

Distribution and Abundance of Other Arthropods.

In 1982, I documented the dramatic reduction in abundance of the native scorpion, *Hadruiroides maculata galapagoensis*, in the areas invaded by *Wasmannia* (Lubin 1984). In 1983, as in the previous year, the numbers of scorpions found in quadrats in the non-infested areas greatly exceeded those in adjacent infested areas (Table 4); the densities of scorpions in both non-infested and infested areas were not significantly different in the two years.

Table 4. Densities of scorpions, *Hadruiroides maculata galapagoensis* and giant centipede, *Scolopendra galapageia*, in quadrats in *Wasmannia*-infested and non-infested areas at Guayabillos, San Salvador I. Densities are shown as numbers of individuals per $m^2 \pm 1$ SD; numbers of quadrats are in parenthesis.

<i>Wasmannia</i>			
	Absent		Present
Scorpions			
1983	0.41 ± 0.34 (10)	0.01 ± 0.02 (10)	
1982	0.40 ± 0.23 (16)	0.06 ± 0.14 (25)	
Centipedes			
1983	0.09 ± 0.11 (10)	0.10 ± 0.07 (10)	

The large native centipede, *Scolopendra galapageia*, did not seem to be affected by the presence of *Wasmannia*. There was no difference in overall abundance in quadrats in infested and non-infested areas (Table 4). Of the 20 *Scolopendra* found in quadrats in the infested area, only 4 were found under rocks

together with groups of *Wasmannia*; this distribution, however, is not significantly different from the distribution of groups of *Wasmannia* in the same quadrats, where 31.5% of rocks and other potential hiding places were infested by ants ($G = 0.696$, $df = 1$, $p > 0.01$).

Sticky traps for flying insects placed in areas infested by *Wasmannia* at Guayabillos in 1982 caught significantly fewer individuals, representing fewer species, than those placed in non-infested areas. Trapping was repeated in 1983 and the results were compared with those for 1982 (Table 5). In 1983, there was no significant difference in the captures between the two areas in either numbers of individuals or numbers of species. Many more individuals were trapped in 1983 than in 1982, an increase that was due almost entirely to the appearance of vast numbers of small midges (Nematocera) of only 2 or 3 species.

Table 5. Comparison of insects caught in aerial sticky traps at Guayabillos in *Wasmannia*-infested (WP) and non-infested (WA) areas at Trágica (WP), on San Salvador I. Shown are total numbers of species trapped, numbers of individuals per trap ± 1 SD and the percent of nematoceros flies (out of the total number of individuals trapped).

1983 (10traps)				1982 (6 traps)		
Spp.		Ind./Trap	%Nem	Spp.	Ind./Trap	%Nem
Guayabillos						
WA	19	113.3+68.2	92.7	28	11.7+5.6	0
WP	17	81.8+60.2	89.1	13	3.5+2.3	0
Trágica						
WP	17	11.4+5.6	72.6	9	5.7+3.1	54.2

While at Guayabillos, the sticky traps caught more individuals of fewer species in 1983, at Trágica, well within the *Wasmannia* zone on San Salvador I., the traps caught greater numbers of individuals of more species than in 1982 (Table 5). As at Guayabillos, the increase in numbers of individuals at Trágica can be attributed to an increase in the numbers of small Nematocera. The difference between the two sites may reflect the influence of El Niño conditions at the two sites: and increase in rainfall and temperature might be expected to have a more positive influence on the humid-zone fauna (Trágica) than on the arid-adapted fauna (Guayabillos).

Discussion

El Niño and the Spread of *Wasmannia*

The changes in physical conditions in the Galápagos Islands during El Niño phenomenon of 1982-83 were so dramatic that it is inconceivable that these changes would not affect virtually all biotic elements, be they terrestrial or aquatic. Nonetheless, it is not easy to distinguish changes caused specifically by El Niño conditions from those only indirectly related or not at all. We lack sufficient baseline information over a long enough period of time to be able to make valid between-year comparisons. Given this limitation, I offer only some conjectures and hypotheses about how the changes documented above might be related to El Niño conditions.

The hot-humid conditions of 1982-83 may have enhanced the spread of *Wasmannia* in two ways: (1) The little fire ant apparently prefers high humidity conditions for foraging activity and for nesting. The highest nest densities occur in the transition zone and in lands under cultivation, particularly in tree crops such as citrus and coffee (L. Endara,

pers. comm., V. Carvajal, 1983). In the arid zone, foragers were more active (more individuals in trails on tree trunks) in the hot, humid season of 1982 than in the dry season (pers. obs.; I. de la Vega, in prep.). *Wasmannia* nests in the arid zone are subject to desiccation during the drier months (Lubin 1984). (2) Higher rainfall, humidity and air temperature during El Niño year favored plant growth. The changes in vegetation were particularly dramatic in the arid and transition zones, where annuals, shrubs and lianas provided almost 100% ground cover. Denser vegetation may have provided more nest sites for *Wasmannia*, as well as more food (nectar, honeydew, insects).

I suggest that the increased scope for foraging activity, more nest sites and more food resulted in a rapid increase in colony populations in *Wasmannia* and in the frequency of dispersal events. The high dispersal rate observed on Santa Cruz I. during El Niño year and the consolidation of *Wasmannia* in areas where the ants were previously scarce lend support to the this hypothesis. On a subjective level, nest densities and foraging activity of the little fire ant in the arid and transition zones appeared much greater during the prolonged hot-humid season of the El Niño year. Houses in the village of Pto. Ayora were invaded by fire ants. Investigators working in the transition zone area of the Giant Tortoise Reserve on Santa Cruz I. reported having to wear foul-weather clothing covering the entire body as protection against hordes of ants in the vegetation (L. Cayot, pers. comm.). The author had a similar experience at the Trágica site in the transition zone of San Salvador I.

I reported earlier that alates of *Wasmannia* did not fly to lights nor did they show up in sticky-trap captures (Lubin 1984). In 1983, nearly 25% of the nests examined at Guayabillos on San Salvador I. had

winged females in them and I frequently observed alates travelling on tree trunks amongst groups of workers (dispersing?). As in the previous year, alates were not caught in any of the aerial sticky traps. However, they were found on several occasions trapped in spider webs (araneid orb-webs), 0.5-1 m above ground, at Pta. Albemarle on the northern tip of Isabela I. and in the arid zone on Santa Cruz I. Possibly some form of aerial dispersal does occur under special conditions. El Niño years may provide appropriate conditions for major dispersal and colonization events by *Wasmannia*, as well as for the consolidation of territories as a result of increases in population size.

It is not clear what prevented *Wasmannia* from colonizing the arid zone on the northern slopes of Santa Cruz I., or why the rate of dispersal into the arid zone of the north-eastern side of San Salvador I. was relatively low. One might expect that the increase in ground cover of grasses and annuals would have favored the expansion of the little fire ant into these areas. There are no baseline data from previous years with which to compare the 1982-83 observations on San Salvador I. The northern boundary of *Wasmannia* on the north slope of Santa Cruz I. has remained apparently stable since the 1976 census. One must remember, however, that the transect lines in the area were at 1 km intervals; if one assumes a dispersal rate of 9 m/year as typical of *Wasmannia* in arid zone habitats (as in the arid zone on San Salvador I.), then in a period of 7 years the ants would have travelled only 63 m and would not have reached the next transect line.

At Pta. Albemarle on the north coast of Isabela I., in 1983, *Wasmannia* occupied an area of approximately 250 m in diameter. A dispersal rate of 9 m/year (or perhaps less in drier years) places the original introduction at about 28 years ago, or about 1955.

This area was used previously as a landing for giant tortoise hunters; it is quite possible that they bought the ants with them from Santa Cruz I.

The Effects of El Niño on Other Arthropods

In the transition zone of San Salvador I., *Solenopsis globularia*, *Cardiocondyla* spp. and *Conomyrma albemarlensis* were found with greater frequency in the dry year of 1982 than in 1983. These are all ground-nesting arid-adapted species that were perhaps affected negatively by the high rainfall and flooding. *Hypoponera opaciceps*, *Paratrechina nesiotes* and *Pheidole* sp. A appeared to increase in abundance in the wet year of 1983. All three species were more common at higher elevations (i.e., more humid climates) on Santa Cruz I. as well as on San Salvador I., and tend to nest either in rotting logs, under bark or in mosses and lichens, rather than directly in the soil.

Another species of ant that seemed to benefit from El Niño conditions was *Tetramorium bicarinatum*. On Española I., this ant became more abundant, particularly in beach and coastal vegetation, during the hot season of 1983 than it had been in previous years (C. Rechten, pers. comm.). In June 1983, I found *T. bicarinatum* nests in virtually every hollow branch or stem at Pta. Suárez on Española I. An intensive search of dead limbs at various sites on Española I. (Pta. Suárez, Gardner Bay, Gardner I., Pta. Cevallos) yielded only nests of *T. bicarinatum* and none at all of the native Española carpenter ant, *Camponotus macilentus*, which also nests in dead limbs. *Tetramorium bicarinatum* was not collected on this island in the expeditions of the 1920's and 30's (Wheeler 1919, 1924, 1933) and may be a relatively recent introduction. Has it displaced the native carpenter ant on this island? *T. bicarinatum* was found also on Santa Fe I., particularly on the wetter, north side of the

island. This species had not been collected previously on Santa Fe and may have spread as a result of El Niño conditions.

The high rainfall and abundance of wet vegetation and fresh water pools provided favorable breeding conditions for numerous small nematoceros flies. Population explosions of one or two species of Nematocera were evident in the arid zone at Pto. Ayora on Santa Cruz I. and at Guayabillos on San Salvador I. Orb weaving spiders (Araneidae) were more abundant in 1983 than in 1982 in these same arid-zone areas. Species that were previously found in the transition and humid zones were now abundant at lower elevations as well (*Leucauge* sp., *Neoscona oaxacensis*, *Gasteracantha cancriformis*). This may be correlated with the abundance of small, flying insects. Some typically arid zone species were either unaffected by El Niño conditions (as was the case with *Hadruiroides maculata* at Guayabillos) or became relatively scarce. Examples of the latter were the small, ant-eating crab-spider, *Tmarus stoltzmanni* (Thomisidae) (Lubin 1983) and the terrestrial hunting spider, *Odo galapagoensis* (Ctenidae), both of which were abundant at Guayabillos in 1982 and rare in 1983.

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PARTE V

EL HOMBRE Y EL
FENOMENO EL NIÑO

MAN AND THE EL NIÑO
EVENT

EFFECTOS DE EL NIÑO EN LA ISLA FLOREANA

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Resumen

Se describe la vida del agricultor en Floreana y cómo el fenómeno El Niño le ha afectado a través de los años desde 1940, cuando el autor llegó a esta isla. El autor encuentra que El Niño de 1982-83 fue el más fuerte que puede recordar porque continuó hasta la época de la garúa; no hubo garúa. Esto no había sucedido anteriormente. En consecuencia no se pudo plantar. El autor sugiere que otro fenómeno El Niño tan fuerte como éste no se ha vivido en Floreana en los últimos cien años. Propone esto en base a la observación de los árboles de piñón (*Jatropha curcas*), los cuáles probablemente fueron plantados por los primeros colonos. Estos árboles murieron a causa de la excesiva humedad en 1982-83.

Summary

*The life of the farmer on Floreana is described and how the El Niño has affected the island through the years since 1940, when the author settled on Floreana. He finds that the El Niño of 1982-83 was the strongest that he can remember as it continued well into the garúa season. As a consequence, the planting for the coming year could not be done. He suggests that another El Niño as strong as this one has not occurred in at least the past 100 years. He bases this opinion on the observation that piñón trees (*Jatropha curcas*) probably planted by the orig-*

inal settlers of this island, died during 1982-83 due to the excessive humidity.

Voy a comenzar a grandes rasgos con mi llegada a la isla. Embarcamos en Guayaquil el 31 de diciembre de 1939 en el *M/V Pinta* y arribamos a Floreana el día 8 de enero de 1940. Desde entonces he venido haciendo observaciones acerca del clima en Floreana en las diversas épocas del año. Es así como me he dado cuenta de que en la época de invierno, o sea en los meses de enero a mayo, el clima es muy variable y caluroso. Nunca se sabe cuando va a empezar el invierno, si lo hay; pero siempre que ha habido y ha sido normal, ha terminado en los primeros días de mayo y a más tardar a mediados. En cambio, lo que sí ha sido seguro y con muy pocas variaciones es el tiempo de las garúas. Por lo regular se inician en julio y se prolongan hasta octubre o noviembre; esto, repito, en el tiempo que tengo de vivir aquí ha sido casi constante, por lo que el agricultor siempre ha confiado en este tiempo para las siembras, en especial de legumbres y cereales. Lo que sí cabe mencionar es que la época de las garúas ha sido muy fría en unos años y en otros abrigada.

Al llegar a la isla ya llovía, pero la vegetación recién principiaba a crecer en alturas de los 200 m hasta el mar y los caminos estaban sumamente claros. Al poco tiempo era asombroso ver con qué rapidez la vegetación iba creciendo; conforme pasaban los días y se intensificaban las lluvias, los caminos y todo el campo iba quedando cubierto de verdor. Una vez que terminaron las lluvias, fue admirable ver con qué rapidez se agostaba la vegetación, y para septiembre ya casi no quedaba ni paja para pasto de los animales.

Floreana es una isla que tiene poca agua. Cuando hay fuertes sequías desaparece totalmente la vegetación pequeña de la parte baja hasta los 200 m de altura; entonces parece como que nunca creciera ni una sola hierba. Pero, tan pronto como se inician las lluvias principia a brotar toda clase de plantas y los árboles, en especial el palo santo (*Bursera graveolens*), se cubren de hojas, lo cual hace que cambie el panorama de la isla. En cambio, en la parte alta o central de la isla la vegetación permanece verde la mayor parte del año, en especial si no se ha presentado una fuerte sequía; porque el tiempo seco, entre invierno y garúa, es de unos dos meses. Es en esta época cuando los frutales principian a madurar; la fruta dura hasta octubre más o menos. Desde el mes de septiembre todos los frutales principian a florecer y por todas partes se respira un aire perfumado por los azahares. Los productos de ciclo corto y que se los cultiva en la garúa se cosechan de octubre a diciembre. Este primer año que pasé aquí fue muy productivo; hubo frutas, legumbres y cereales en abundancia, lo mismo que papas, camotes, yuca, bananos y muchos otros productos.

Un aspecto que me llamó la atención cuando llegué fue que encontré cercos vivos de piñón (*Jatropha curcas*), que probablemente fueron plantados por los primeros colonos, pues se habían convertido en árboles corpulentos. Si los primeros colonos llegaron a esta isla en 1832 (Black, 1984), estos árboles tienen más de un siglo. Estos árboles son de mucha utilidad para las cercas, pues una vez plantados crecen con mucha facilidad cuando hay humedad y además son muy resistentes a la sequía.

Debo consignar además que en la parte NE de la isla se encuentra un cerro, al que le hemos denominado el "Cerro Laguna". El nombre se debe a que el cráter de dicho cerro está completamente cerrado y en el fondo existe una laguna. En 1941, más o menos

al año del invierno de 1940, fuimos de paseo hasta el puerto de las Cuevas con un hermano mío que entonces me acompañaba. Al regreso se nos terminó el agua, pero con gran suerte cogimos un trillo o sendero de animales salvajes; este trillo nos llevó a un cerro. Una vez que ascendimos unos 50 m, divisamos con gran sorpresa una laguna en el fondo del cráter, la cual cubría casi toda la superficie del mismo, que es de aproximadamente unos 200 m de diámetro. Bajamos lo más rápido que pudimos a probar el agua, viendo que era muy buena, llenamos nuestras cantimploras y nos bañamos a gusto.

Los años siguientes fueron muy variables en lo que se refiere a inviernos. Hubo años en que no cayó más de uno o dos aguaceros en todo el tiempo invernal. Otros en cambio fueron tan fuertes como mi primer invierno en Floreana, el de 1940. Así por ejemplo, en 1953 durante el invierno llovía día y noche, las ratas se propagaron en forma alarmante y desde entonces no se ha podido cultivar con tranquilidad. Desde entonces ha sido necesario combatir las para poder cosechar lo que se cultiva. Otro invierno bastante fuerte fue el de 1975, el cual se caracterizó porque no llovía en forma intermitente, sino que caía un aguacero fortísimo en cada cambio de las fases lunares, o sea que llovía cada siete días más o menos. Como resultado se produjeron muchos daños en los caminos, pero no hubo perjuicio a la agricultura.

En el transcurso de 1982 recibimos el aviso por diferentes medios, de que se aproximaba un Niño muy grande. Esta noticia la recibimos con beneplácito, pues eran ya varios los años que habíamos soportado escasez de agua; nunca pensamos que sería tan fuerte como lo fue.

El Niño 1982-83 se inició el 15 de noviembre con una precipitación no muy fuerte. Conforme transcurría el tiempo aumentaban las precipitaciones; esto

ocasionó la pérdida de casi todas las cosechas, porque con tanta lluvia no se pudo recogerlas. Pensábamos que febrero, marzo y abril serían los meses más fuertes, pero todas nuestras esperanzas fueron vanas. Ya para entonces todos los caminos estaban inundados tanto en las partes bajas como en la parte central. Es en la parte central de la isla en donde se encuentran las fincas. Esta región tiene terrenos planos en su mayoría y se inundaron con mayor facilidad. Por la cantidad de agua muchos árboles empezaron a pudrirse, en especial el piñón (*Jatropha curcas*). Estos árboles no han sido afectados en inviernos anteriores, pero en éste se pudrieron casi en su totalidad, causando la destrucción de las cercas de todas las fincas. De esta circunstancia se puede deducir que un Niño con la intensidad de éste no ha habido en más de cien años en Floreana.

Durante este Niño fue algo asombroso ver cómo creció la vegetación en toda la isla. En el puerto y hasta unos 60 m sobre el nivel del mar crecieron especialmente las plantas trepadoras y cubrieron a casi todos los árboles, en particular a los algarrobos, dando un aspecto fabuloso a la isla. La isla se había convertido en una pequeña selva llena de montículos verdes; por debajo de toda esta vegetación corría el agua hasta el mar.

Aquí en mi casa que está a unos 30 minutos de la playa y a unos 120 m sobre el nivel del mar, tenemos una pequeña fuente de agua. Con la abundancia de agua, brotó el agua por diferentes sitios y formó dos encañadas. Estas se unieron a unos 100 m de distancia y formaron un pequeño río que corría hasta el mar. Estas corrientes han arrastrado toda la tierra que encontraban a su paso y fueron formando un lecho de más de un metro de profundidad y algunos de ancho. Si no ahondaron más fue porque ya llegaron a la capa rocosa. En el mar, el agua dulce se adentraba unos 100 m y enturbiaba toda el agua de la costa.

Por estas corrientes que comenzaron a correr regularmente subieron una gran cantidad de carmarones (*Macrobrachium*) y unos peces. Estos han subido hasta nuestra fuente y hoy que ha pasado El Niño y ya no corre agua hasta el mar, seguimos encontrando camarones y pecesitos.

Con tanta agua que se acumuló en la parte central de la isla, parecía que todos los árboles frutales iban a morir, porque tanto naranjos, limoneros como guayabos tenían las hojas mustias o carecían de ellas. Tampoco florecieron, por lo que el próximo año no tendremos cosecha de los frutales.

Los animales domésticos también fueron afectados. Tanto caballos como burros y ganado vacuno se imposibilitaban al dañárseles los cascos a causa de la mucha humedad. A los recién nacidos se debía ponerles bajo techo pues de lo contrario se les caía el pelo y morían de frío.

Los meses de junio y julio creo yo que fueron los meses más fuertes de El Niño, tal cosa jamás había sucedido. No sólo había lluvia sino también tempestades de truenos y relámpagos que eran tan fuertes y seguidos que parecían como si el Cerro Pajas se desplomara. Debo mencionar también que todas las construcciones de cemento de la isla se cuartearon; desconozco si ésto fue debido a la humedad excesiva o a movimientos terráqueos.

Los caminos se dañaron tanto que en su mayoría se convirtieron en encañadas y a diario era necesario encontrar por donde caminar. Para ilustrar mejor diré que de mi casa al puerto se hacen 30 minutos, pero ahora empleábamos casi una hora. Ir a las fincas era peor, porque en la parte plana los caminos se habían convertido en fango. Por ésto, tanto gente como animales nos hundíamos hasta las rodillas y se debía caminar con mucha precaución. Esta situación no la habíamos vivido en inviernos anteriores.

En cuanto a insectos, llamó mucho la atención la ausencia absoluta de mosquitos, los cuales en otros años con las primeras lluvias se alborotan y abundan, tanto en las partes bajas como altas. En contraste, durante febrero y marzo asomó un tipo de zancudo grande pero inofensivo. A éstos nunca antes los habíamos detectado. Fastidiaban por su gran cantidad, se acumulaban en puertas, paredes y ventanas en tal cantidad que todos los días se debía recogerlos con la escoba. Tal como aparecieron, igualmente desaparecieron. Luego vino una invasión de mosquitos diminutos, los cuales no eran detenidos ni por las mallas de las ventanas. Esta invasión también duró poco.

Los insectos también atacaron a los árboles frutales. En mi propiedad tenemos algunos árboles de ciruelo (*Spondias purpurea*) y desde hace unos tres años no teníamos cosecha por falta de agua. Esta fruta se cosecha por lo general de enero a abril. Con las lluvias de El Niño los árboles se recuperaron y se cubrieron de hojas; sin embargo, no florecieron sino hasta agosto y septiembre. Esperábamos una buena cosecha, pero las frutas muy pequeñas y tiernas se amarillaron y empezaron a caer. Un día cojí unas frutas enfermas y las abrí, encontrando que en la pepa misma había unos pequeños gusanos. A consecuencia de ésto se ha perdido por lo menos el 50% de la cosecha.

Otro aspecto desventajoso ha sido la proliferación de ratas. Estas han llegado al extremo de comerse todo el maíz de semilla que se depositaba en la tierra. Para controlarlas ha sido necesario usar mucho veneno, lo cual perjudica al agricultor ya que pierde tiempo y dinero. Esta proliferación alarmante de ratas se debe a que han tenido abundante comida y con tanta vegetación podían esconderse de gatos y lechuzas.

Cuando fueron cesando las lluvias y la tierra iba drenando, la vegetación se recuperó. Por doquier se velan brotes nuevos con relucientes hojas verdes los cuales le animaban a uno a seguir luchando, después de haber soportado ocho meses de lluvias torrenciales.

Después de un Niño tan fuerte, teníamos curiosidad de saber cuál era la cantidad de agua que se había recogido en el Cerro Laguna, el cual se encontraba seco por algunos años. Aprovechando que se podía caminar con mayor facilidad, se fueron mis hijos y vinieron sorprendidos a conversar que todo el cráter estaba cubierto de agua y en parte hasta las paredes mismas.

Lo más difícil de todo ha sido que por primera vez en mis 44 años de vivir en Floreana no llegó la garúa tan esperada por los agricultores y por lo tanto no se pudo sembrar absolutamente nada. Esta es una consecuencia de El Niño, que ha afectado enormemente a la economía del colono que se basa en la agricultura.

A grandes rasgos he dado a conocer los daños y perjuicios que ocasionó El Niño de 1982-83. Este fenómeno así como trajo daños y sustos, también nos ha traído un poco de tranquilidad con el abastecimiento de agua a las fuentes. La reserva de agua en la tierra va a durar por algunos años, si al menos los años venideros no son tan secos.

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EL PARQUE INFANTIL Y EL FENOMENO EL NIÑO EN PUERTO BAQUERIZO MORENO, ISLA SAN CRISTOBAL: UNA LECCION EN PLANIFICACION

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Galápagos, Ecuador

Resumen

Las fuertes lluvias de El Niño 1982-83 destruyeron el parque infantil, de reciente construcción en Puerto Baquerizo Moreno, Isla San Cristóbal. Las lluvias también inundaron algunas calles y casas en la población. Una gran pared de concreto que se construyó para impedir el flujo del agua de mar tuvo que ser derribada. La planificación ajena al ambiente había pasado por alto el lecho seco que por mucho tiempo entraba a la bahía. Estos daños materiales representan una lección: Respetar el arte de la naturaleza.

Summary

The heavy rains of El Niño 1982-83 destroyed the recently constructed children's playground in Puerto Baquerizo Moreno, San Cristóbal. The rains also flooded some streets and houses in the village. A huge concrete wall, constructed to prevent the free flow of water from the sea, had to be dismantled. Desk planning overlooked the dry stream bed, which for ages entered the bay. These damages constitute a lesson, to respect the art of nature.

Introducción

El fenómeno El Niño se hace presente en las Islas Galápagos todos los años entre los meses de diciembre y marzo; pero con mayor intensidad y con perfiles destructivos a intervalos irregulares. De los últimos registros, se destacan los siguientes años por el fenómeno El Niño: 1952-53, 1957-58 y 1982-83.

A todos los años en que El Niño se presenta con mayor intensidad se los ha llamado "Años de Choque" y están caracterizados por copiosas y prolongadas lluvias. La temperatura del agua del mar se eleva bastante por encima de lo normal (*véase el artículo por Robalino*). En el interior de las islas los efectos de la erosión son notorios. Igualmente son conocidos los daños sobre la biota, especialmente marina o que depende del mar, como son las aves marinas (*véanse los artículos de Rechten, Grove, y Robinson*).

Las zonas agrarias son afectadas grandemente por el deslizamiento de capas de tierra que arrasaron con los cultivos. Hay anegación de terrenos, destrucción de casas e inundaciones. Las vías carrosables se destruyen, cortando así las comunicaciones entre pueblos y caseríos. Se presenta carestía de productos, lo cual ocasiona desabastecimiento de alimentos en las zonas afectadas, movimientos de gente hacia los puertos y finalmente aumento de enfermedades, especialmente en la población infantil (*véanse los artículos de Navarrete y otros y de Robalino y otros*).

El fenómeno El Niño en 1982-83 fue especialmente fuerte. En el pluviómetro de la Soledad (I. San Cristóbal), la precipitación total sobrepasó los 1200 mm en un solo mes, diciembre de 1982. En términos normales esa cantidad casi igualaría al total de lluvias de un año. Este fenómeno El Niño representa una advertencia a fin de que se tome en cuenta para

la planificación de obras que tienen que enfrentarse necesariamente con él y que no tengamos que lamentar pérdidas, como las ocurridas este año.

La inundación en Puerto Baquerizo Moreno

Entre los días 16 y 17 de diciembre de 1982, tuvo lugar un tremendo aguacero que duró alrededor de 15 horas consecutivas. El pluviómetro de El Progreso señaló 137 mm. Todas las cañadas de la isla arrojaron cantidades enormes de agua al mar. Las cañadas secas, especialmente las que cruzan la población, se reactivaron y siguieron su cauce normal, y así se rompieron caminos, avenidas y puentes. También se pusieron en peligro a ciertas construcciones.

Una de las obras más afectadas por el evento El Niño fue el parque infantil "Jaime Roldós Aguilera", recientemente inaugurado. La construcción de este parque infantil tuvo como elemento motivador la preexistencia de una poza de aguas marinas, que en los grandes aguajes recibía el desbordamiento del mar y en los inviernos fuertes daba curso libre a las torrentosas aguas que se precipitaban por medio de una cañada, sin provocar daños a su paso. Pasado el tiempo invernal, la poza quedaba aislada, recibiendo los desagües de los vecindarios, basuras y polvo, razón por la cual presentaba un aspecto desagradable a la vista y era mal oliente, convirtiéndose de cierta manera en un foco de infección.

El proyecto de evitar esto y de convertirlo en un lugar de recreación fue plausible; lo que no resultó fueron los métodos. Se limitó a la poza con muros de piedra. Se levantó un puente de hormigón, lo suficientemente alto, ancho y largo como para encauzar una cantidad de agua en años normales, pero no para los eventos El Niño que de vez en cuando se hacen presentes, como éste, en el que el torrente fue

tan grande que se desbordó el agua, poniendo en peligro a la construcción.

Para la entrada y salida del agua se hizo un largo canal, pero de apenas 3 m de ancho y de una altura que va desde 0 m hasta 3 m. Además no se siguió el cauce normal tanto del brazo de mar como de la cañada, sino hacia un costado de la poza y se cerró la entrada y salida natural del agua con un muro de mampostería. En este sitio había antes un puente de madera que prestó servicios por algunos años. El muro era alto como para que no pasen las olas en los grandes agujeros, y tan profundo como para que resista los golpes del agua, aunque sentado sobre arena, dos errores fundamentales que al presentarse el fenómeno El Niño, causaron la destrucción de la obra.

La cantidad de agua que bajó por la cañada fue tan grande que se desbordó por encima del puente. No siendo suficiente el canal artificial de desagüe, empezó a llenarse la poza. Como el muro de contención era más alto, el agua inundó las calles, luego las casas cuyo nivel estaba más bajo que el muro. Así, penetró en los almacenes de los señores Sarmiento y Cox y en el domicilio de la Sra. Carmela Palma, sufriendo este último pérdidas de consideración.

Ante estas circunstancias, las autoridades locales ordenaron la demolición de la parte central del muro. La ruptura se realizó por el lugar de salida natural que tenía la poza. Minutos después la poza se vació, rebajando notablemente el nivel de agua también en almacenes y viviendas, aunque fue necesario romper parte de las aceras porque no tenían desagües o no eran suficientes.

Este es un hecho muy significativo para autoridades, técnicos, ingenieros y pueblo. Galápagos está fuera de lo ordinario y necesita trato especial. El

parque infantil y el cerramiento de la poza fueron diseñados en un escritorio ajeno a la realidad natural de Galápagos.

Nuevos efectos del fenómeno El Niño en Puerto Baquerizo Moreno

El día 23 de Marzo de 1983, desde las 3:00 horas hasta las 9:00 horas, y desde las 19 horas hasta las 14:30 horas del día 24, la población de Puerto Baquerizo Moreno fue castigada duramente por una intensa lluvia. Este aguacero puso en peligro a algunos edificios e inundó nuevamente las viviendas aledañas a la poza del parque infantil, al igual que los almacenes Sarmiento, Cox y C. Palma, produciendo nuevas pérdidas. Todo el material (ripio y arena) que el Municipio colocó en las calles, no obstante la primera advertencia natural del evento, fue arrastrado, efectuándose esta vez el relleno parcial de la poza, a la que tapó casi hasta la garita. Esto significa que la poza, vuelve a su estado primitivo, llenando aceleradamente los vacíos hechos por la mano del hombre. Como las aceras que circundan al Parque "Jaime Roldós Aguilera" impidieron el libre paso de la crecida, cuyo cauce era la avenida "Armada Nacional", el agua invadió las propiedades particulares como el caso de la familia Mora Jaime, entre otras.

A las 21:00 horas del día 23, mientras una parte de la población, la menos afectada, seguía con interés en la televisión local la trama de una película "Crimen por prescripción", se interrumpió la transmisión para anunciar el peligro en que se encontraban algunas familias, inclusive la misma televisora, por lo que se pedía ayuda al Cuerpo de Bomberos y a las demás personas. Fue el momento dramático del evento: Todas las calles se había convertido en ríos, particularmente las arterias principales como Española, 12 de Febrero, Quito, y Armada Nacional. Detrás de la Misión había tal caudal que rebasó los desagua-

deros, precipitándose a los patios, amenazando con inundar el local de la televisora.

La calle Northia, comprendida entre la Quito y Armada Nacional era un solo río de aguas turbias que se lanzaban en cascadas y chorreras por encima de la vereda para unirse con el torrente de la poza y parque ya inundados. El paso era más que imposible, peligroso. Los desagües cilíndricos hechos con grandes piezas de hierro tol para permitir el paso de vehículos hacia la playa Mann en la cañada cercana a la propiedad del señor Becerra, lo mismo que en la cañada que baña las propiedades del Servicio del Parque Nacional Galápagos, fueron sacados de raíz y arrastrados como basura. De esta manera el paso quedó peor que antes por las excavaciones hechas.

El barrio "Las Peñas" también sufrió destrozos e inundaciones. Hubo cuatro crecidas cañadas que después de romper las calles e inundar el sector se precipitaron a la orilla del mar. Estas son: la calle contigua a la Isabela, la calle Carlos Mora, la calle Enrique Vallejo y la calle al extremo del barrio. La avenida Armada Nacional, que recibió el desbordamiento de la cañada, fue destruída con parte de sus aceras.

Hay una pregunta: ¿Será este invierno el más fuerte acaecido en Galápagos? Es posible; aunque me inclino a pensar que este evento El Niño no ha sido más intenso que el de alguno o algunos años pasados. Por algo se le viene llamando "Año de Choque", año de desastres. Lo que sí creo es que lo hemos sentido más fuerte y destructor que en otros años, porque nosotros hemos tomado parte en provocar estos desórdenes naturales.

Ejemplo muy claro es el parque infantil. Las aceras sirven por un lado como cauce artificial de las aguas; y por otro mantienen a las aguas estancadas dentro de las propiedades. Las calles trazadas

con el plano en la mano, con nivel y plomada, impecablemente rectas, sin detenerse ante los obstáculos, derrumbando acantilados y rellenando quebradas han cambiado el curso natural de las aguas. El material usado en el relleno de las calles, ripio y arena, es fácil de ser cargado por el agua y depositado a su capricho en lugares no convenientes, una parte y otra lanzada al mar, cuya sedimentación aceleramos con perjuicio y alteración de la vida marina de nuestra Bahía.

Otra razón poderosa por la que nosotros hemos sentido más destructor este año, es el aumento de construcciones de cemento. Sus paredes contra las que chocan las crecidas, desviando las aguas hacia lugares no abiertos, producen el estancamiento o acumulación en un solo torrente, con las consecuencias anotadas.

¿Puede darse una lección más clara de la naturaleza para arquitectos, ingenieros, urbanistas, diseñadores o simplemente habitantes de Galápagos?

CAMBIOS EN LA CARRETERA PUERTO AYORA-CANAL
DE ITABACA, EN EL SUELO, LA VEGETACION Y LA
ABUNDANCIA DE HORMIGAS COLORADAS EN AREAS DE
COLOÑIZACION DE LA ISLA SANTA CRUZ, GALAPAGOS

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Resumen

Durante El Niño, la carretera Puerto Ayora-Canal de Itabaca sufrió pérdida del material de sub-base, aparición de cañadas y se colectaron aguas superficiales sobre la calzada. Las autoridades prestaron atención permanente para el mantenimiento de esta vía. En las fincas de la parte alta hubo erosión y en la mayoría de fincas aparecieron cañadas por las que corrió gran cantidad de agua que se llevó el suelo fértil. En Puerto Ayora crecieron plantas durante El Niño que normalmente sólo crecen en la zona húmeda. Plantas propias de la zona seca, en cambio, se murieron o perdieron sus hojas. Los habitantes de este Puerto se vieron afectados por el aumento de hormigas coloradas.

Summary

During El Niño , the Puerto Ayora-Canal de Itabaca road suffered a loss of its basement material, was crossed by streams and water collected on the highway's surface. Local authorities had to pay constant attention to the maintenance of the highway and had to repair it frequently. In the farmlands,

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streams appeared in which enormous quantities of water ran, carrying away the fertile soil. In Puerto Ayora plants of the more humid highlands grew. In contrast, plants typical of the arid zone died or lost leaves. The inhabitants of Puerto Ayora were plagued by an increase in fire ants.

El Niño 1982-83 trajo un incremento de las lluvias y un aumento de las temperaturas del aire y del mar en la Isla Santa Cruz (ver el trabajo de M. Robalino en este volumen). Además, hubo cambios en la dirección y velocidad del viento. La dirección predominante del SSE cambió durante los meses afectados por El Niño, registrándose otras direcciones. Estas modificaciones del clima dieron origen a otras alteraciones del medio ambiente. Así, se modificaron el suelo, la vegetación y los caminos. El conjunto de cambios afectó al hombre y a sus actividades.

En el presente trabajo, el Quinto Curso del Colegio Nacional Galápagos se propuso averiguar el impacto de El Niño en el medio ambiente de la Isla Santa Cruz, con relación a los temas que se señalan a continuación. Los cambios en la carretera Puerto Ayora-Canal de Itabaca fueron investigados por D. Navarrete. El efecto en el aspecto físico del suelo de la zona rural fue estudiado por E. Navarrete. M. Barrera y M. Cárdenas investigaron los cambios en la flora de Puerto Ayora. Finalmente, el estudio sobre los cambios en la distribución y abundancia de la hormiga colorada *Wasmannia auropunctata*, estuvo a cargo de G. Véliz y A. Vargas. Los cambios en el clima, en base a los datos meteorológicos de la Estación Darwin, fueron estudiados por M. Jaramillo y H. Vásquez. Estos cambios no se reportan en detalle, pues han sido tratados ya por M. Robalino en este volumen. La Licenciada M. López de Buitrón coordinó el trabajo.

Este estudio está basado en la información obtenida mediante observación, entrevistas con los pobladores y aplicación de encuestas.

Cambios en la carretera Puerto Ayora-Canal de Itabaca

Las lluvias de octubre de 1982 a julio de 1983 causaron daños de consideración en la carretera Puerto Ayora-Canal de Itabaca. Esta carretera es de fundamental importancia para la economía de la Isla Santa Cruz. La situación recibió la atención de las autoridades del Instituto Nacional Galápagos (INGALA), la Ilustre Municipalidad y la Junta Cívica, quienes brindaron todo el apoyo para repararla y mantenerla en estado transitable. Los daños en esta carretera se describen por sectores.

1. Sector Puerto Ayora-Bellavista.

En esta parte se destruyeron aproximadamente 4 km de la carretera. El material de base y sub-base que aparentemente no estaba bien compactado fue arrastrado por el caudal de agua. Se formaron cañadas que interrumpieron la vía y la dejaron intransitable. Una cañada se formó en el km 4, otra se formó en el recinto Bellavista. Aquí, el curso del agua tuvo que ser desviado y se construyó un puente, pues el caudal del agua era muy fuerte y las alcantarillas no lo soportaron.

2. Sector Bellavista-Santa Rosa.

Aproximadamente 6 km de carretera se dañaron en este sector. Aparecieron numerosas cañadas que cruzaban la vía. Se formaron cunetas a los lados de la carretera y hubo arrastre del material de sub-base.

3. Sector Santa Rosa-Itabaca.

Los kilómetros 35 al 42 de la carretera fueron totalmente destruidos por el invierno. En este tramo el suelo es plano. Con las lluvias, se colectaban grandes cantidades de agua que no se filtraban a

través de la tierra arcillosa y cubrían totalmente el carretero. El INGALA construyó 13 alcantarillas para drenaje del agua. Todo este tramo de la carretera fue destruido y se impedía el paso vehicular. Algunos sectores estaban en constante reparación.

La magnitud de los daños en esta vía fue grande. Las reparaciones consistieron en la colocación de nuevo material, la construcción del desvío de agua en el sector de Bellavista para impedir el daño a la vía. Además se realizaron construcciones laterales para la evacuación de aguas superficiales y se colocaron alcantarillas.

Alteraciones en el aspecto del suelo en la zona rural de Santa Cruz

La parte alta de Santa Cruz recibió fuertes precipitaciones de octubre de 1982 a julio de 1983, las cuales causaron erosión. Los resultados que se reportan están basados en una encuesta realizada a 42 propietarios de fincas que se encuentran en los sectores de Salasaca, Santa Rosa, El Carmen, El Occidente, Bellavista, El Camote y El Cascajo.

Sólo en tres fincas no se formaron cañadas. En las 39 restantes aparecieron cañadas por las que corrió abundante agua. En algunos sectores existían algunas cañadas antiguas por las que en otros años ha corrido el agua durante el invierno, pero algunas cañadas fueron nuevas. El número de cañadas por finca varió entre una cinco. La formación de estas cañadas trajo consigo erosión con pérdida del suelo fértil, dejando al descubierto el subsuelo pedregoso. Además se formaron pozas y hubo derrumbes.

Los sitios más afectados correspondieron a aquellos en donde habían cauces antiguos para el agua. Estos sitios corresponden a algunos sectores en El

Camote y El Cascajo y principalmente el centro de Bellavista por donde corrió un gran caudal de agua.

Cambios en la Flora de Puerto Ayora

Las alteraciones climáticas de El Niño produjeron cambios en la geografía vegetal, especialmente de la zona seca de la isla (de los 15 a los 120 m de altura). Así se notó la aparición espontánea de naranjilla, llantén, hierba mora, ají, aguacate, pasto elefante, verbena y otras plantas tales como maracuyá, mango y zapallo. Estas plantas crecen normalmente en la zona húmeda de la isla, pero no en la seca. Los nombres científicos de estas plantas se dan en la Tabla 1.

Tabla 1. Nuevos registros de plantas en Puerto Ayora. Basado en entrevistas a 85 domicilios. (n = 85)

Nombre Común	Nombre Científico	Porcentaje de Presencia Jul-Ago/83	Ene/84
Naranjilla	<i>Solanum quitoense</i>	58	0
Llantén	<i>Plantago major</i>	66	0
Hierba mora	<i>Solanum nodiflorum</i>	33	1
Ají	<i>Capsicum sp.</i>	80	0
Aguacate	<i>Persea americana</i>	9	0
Pasto	<i>Pennisetum purpureum</i>	7	0
Verbena	<i>Verbena sp.</i>	27	0
Otras*		33	0

*Plantas tales como mango, maracuyá, zapallo y otras.

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Esta tabla también muestra el porcentaje de presencia de estas plantas en los domicilios de Puerto Ayora. Estos porcentajes se han calculado en base a las encuestas realizadas a 85 domicilios del Puerto. Los resultados de la encuesta señalan que estas plantas crecieron espontáneamente en la parte baja durante El Niño. Una vez que cesaron las lluvias, esas plantas han desaparecido (Tabla 1). Se reportan también los casos en que se dieron estos nuevos registros (Tabla 1).

Por la excesiva humedad, plantas propias de la zona seca se vieron afectadas. Los cambios que se notaron fueron la muerte, la putrefacción de la planta, o la pérdida de hojas. La Tabla 2 muestra los resultados de la encuesta. Los almendros que crecen tanto en la zona seca como en la húmeda perdieron hojas, y las opuntias, que son típicas de la zona seca, se cayeron.

El análisis de la presencia de nuevas plantas y las alteraciones causadas a las plantas propias de la zona seca nos indican que hubo cambios significativos en la vegetación de Puerto Ayora durante El Niño.

Tabla 2. Plantas que murieron, se pudrieron o perdieron hojas. Basado en entrevistas a 85 domicilios en Puerto Ayora.

Nombre Común	Nombre Científico	Dañó en porcentaje (n = 85)
Muyuyo	<i>Cordia lutea</i>	9
Tamarindo	<i>Tamarindus indica</i>	8
Almendro	<i>Terminalia catappa</i>	14
Cactus	<i>Opuntia echios</i>	37

Cambios en la distribución y abundancia de la hormiga colorada, *Wasmannia auropunctata* en Puerto Ayora

En el presente capítulo se trata de determinar el impacto del fenómeno El Niño en la distribución y abundancia de la hormiga colorada en Puerto Ayora. Hemos comparado la distribución de esta hormiga en el año de El Niño con el anterior y hemos investigado sobre los sitios dentro y fuera de las casas donde hay infestación de hormigas.

La hormiga colorada fue introducida a Santa Cruz entre 1910 a 1920 y desde entonces empezó a extenderse desde la zona húmeda hacia la zona seca, infestando en la actualidad gran parte de esta isla, con excepción de la zona de *Miconia*. Esta hormiga causa molestias al hombre por sus picaduras. A esto se suma un problema más grave, que es el impacto ecológico que esta especie introducida tiene sobre los ecosistemas galapagueños.

Tabla 3. Sitios del domicilio en donde está localizada la hormiga colorada, *Wasmannia auropunctata*. Total de domicilios = 65

Sitios	Número de Domicilios	Porcentaje
Casa	9	14
Patio	8	12
Lavandería	2	3
Jardín	5	8
Toda la Propiedad	41	63

Para este trabajo entrevistamos a 65 familias. Los resultados señalan que hubo un gran aumento de estas hormigas durante El Niño. Los pobladores afirman que este aumento de hormigas dentro y fuera

de las casas se debió a las lluvias y a la excesiva humedad. Siete de los 65 domicilios encuestados afirmaron haber tenido hormigas en el invierno 1981-1982. En cambio en el invierno 1982-83, todos los 65 domicilios estuvieron afectados por esta hormiga. Estos resultados dan una clara indicación de la expansión poblacional que experimentó esta especie.

Tratamos de averiguar los lugares de los domicilios en donde se encontraron hormigas. La Tabla 3 muestra los resultados. Las hormigas se distribuyeron por toda la propiedad. Un 91% de los encuestados afirmaron que hubo muchísimas hormigas. Sólo dos familias (3%) aseguraron tener pocas hormigas en su domicilio.

Los resultados de este trabajo muestran el aumento poblacional de la hormiga colorada a consecuencia del fenómeno El Niño.

EFFECTOS DE EL NIÑO 1982-1983 EN EL HOMBRE Y SUS ACTIVIDADES EN LA ISLA SANTA CRUZ, GALAPAGOS

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Resumen

En la Isla Santa Cruz, El Niño tuvo efectos negativos en la agricultura y ganadería, en la pesca y en las operaciones de turismo. Hubo efectos en la salud de los pobladores que se manifestaron en la aparición de enfermedades gastrointestinales, de la piel, del oído, y en resfríos. Las lluvias, vientos y truenos causaron temor en los pobladores tanto de la parte alta como de la baja.

Summary

El Niño 1982-1983 affected in a negative way agriculture and cattle raising on Santa Cruz Island. Fishing operations as well as tourism were also affected. There were effects in the health of inhabitants. Diseases of the gastrointestinal tract, of the skin, the ear, and colds were common. Rain, wind, and thunder frightened people both in the highlands and in the lowlands.

En 1982-1983 El Niño se presentó con una fuerza desacostumbrada en Galápagos, de modo que sus efectos difícilmente podrán ser olvidados por quienes, como

nosotros, hemos sentido su furia y poder. Ahora que este fenómeno ha cesado, hemos decidido llevar a cabo una evaluación del impacto del mismo en las poblaciones de la Isla Santa Cruz. Para las personas que hacemos el Quinto Curso del Colegio Nacional Galápagos, este trabajo tiene el valor de ofrecer los resultados que hemos obtenido por nuestro propio esfuerzo.

Los aspectos investigados fueron los siguientes: Los efectos de El Niño en el sector agropecuario. Esta parte de la investigación estuvo a cargo de Enrique Robalino. Liby Goumaz investigó los efectos en el sector pesquero. Leonardo Alvear estudió el impacto de El Niño en la operación turística de los residentes. La investigación sobre el efecto en la salud de los pobladores de las zonas urbana y rural de Santa Cruz fue realizada por Alexandra Caiza, Lupe Castañeda y Washington Martínez. Finalmente, Wilma Patiño investigó sobre la reacción de los pobladores de la isla ante el fenómeno. La investigación estuvo coordinada por la Licenciada María López de Buitrón.

Metodología

la información para este trabajo se la obtuvo en base a observaciones y a entrevistas con los pobladores. También se aplicaron encuestas. Los resultados fueron tabulados y se calcularon porcentajes.

Efectos en el sector agropecuario

El sector agropecuario de la Isla Santa Cruz comprende aproximadamente a 120 fincas, las cuales son en su mayoría de producción mixta; esto es, ganadera y agrícola. Se entrevistó y encuestó a los propietarios de 66 fincas que están distribuidas en la parte alta de Santa Cruz, en las siguientes localidades: Salasaca, Santa Rosa, El Carmen, El Occiden-

te, Bellavista, El Camote y El Cascajo. Además se entrevistó a 44 propietarios de casas en Bellavista.

Muchas viviendas fueron afectadas por los fuertes aguaceros y por los vientos. En Bellavista, el 34% de las viviendas sufrieron daños (del total de 44 casas encuestadas).

Los daños causados por El Niño en las 66 fincas se resumen en la Tabla 1. Por la mucha humedad se afectaron los pastos, que se pudrieron o fueron arrastrados por el agua. Las cercas de las fincas tienen con frecuencia como soporte a las plantas de piñón *Jatropha curcas*. Estas se pudrieron y murieron a consecuencia de las aguas lluvia que no se filtraban. Igualmente por la excesiva humedad murieron muchos árboles de aguacate y se afectaron varios cultivos.

Tabla 1 Daños causados por El Niño en el sector agropecuario. Total de fincas = 66.

Daño en	Porcentaje de fincas		
	Afectadas	No afectadas	Sin respuesta
Cercas	55	33	12
Pastos	41	54	5
Cultivos	60	40	0
Ganado	52	36	12

En cuanto al ganado vacuno, han ocurrido numerosas pérdidas debido especialmente a la muerte de terneros, pero también de reses adultas. En los adultos se presentaron principalmente enfermedades a los cascos. Al cuantificar estas pérdidas se encontró que en 15 fincas se murieron de 1 a 5 cabezas de

de ganado (23%). Siete propietarios (11%) reportaron la muerte de 5 a 10 cabezas de ganado. En igual porcentaje se encuentran quienes perdieron de 10 a 20 cabezas de ganado. Cinco propietarios perdieron más de 20 cabezas de ganado (8%). No brindaron información 8 personas y 24 (36%) no sufrieron pérdidas.

En conclusión, el sector agrícola y ganadero experimentó pérdidas a causa de las lluvias persistentes.

Efectos en el sector pesquero

La pesca ha jugado un papel importante en el aspecto social y económico del Puerto Ayora, pues muchos de los primeros habitantes fueron pescadores. En la actualidad más personas se dedican al turismo que a la pesca. El total de pescadores es de aproximadamente 30, de los cuales se pudo entrevistar a 12; los demás estaban navegando.

La Tabla 2 muestra que la mayoría de los pescadores encuestados pescan langosta. En Santa Cruz existen embarcaciones pequeñas que se dedican a pescar langosta. Los buzos extraen además langostinos, coral blanco y negro, concha perla y otros. La pesca de la langosta se realiza por la noche.

Tabla 2. Tipos de pesca en Puerto Ayora. Total de pescadores encuestados = 12.

Tipo de pesca	Número de pescadores	Porcentaje
Langosta	5	42
Bacalao	3	25
Mixta (bacalao y langosta)	3	25
Lisa	1	8

Durante los meses afectados hubo escasez de langosta, pues fue muy difícil ver a cierta distancia dentro del mar ya que el agua estaba turbia y tenía un color verde.

La pesca de bacalao se realiza en botes pequeños con capacidad de 40 toneladas y por períodos de 20 días aproximadamente, en los meses de enero a marzo. Los pescadores dicen que en ese tiempo el bacalao se acerca a la orilla. La pesca del bacalao sufrió pérdidas durante el período de El Niño, pues este pez requiere de aguas frías. Además, el mar se embraveció y no permitió hacer las faenas de pesca con tranquilidad. Por otro lado, las abundantes lluvias no facilitaron el secado del pescado salado. Para complicar el asunto, hubo pérdidas adicionales pues el pescado seco se dañó en la travesía de Galápagos a Guayaquil por la humedad alta. Las autoridades de sanidad de Guayaquil prohibieron la venta de tal pescado.

La lisa es explotada en Santa Cruz por una sola persona, el Sr. Segundo Asencio, quien pesca de 09:00 a 12:00 horas. La lisa es abundante de enero a julio. El mayor problema en la pesca de la lisa se debió a las condiciones agitadas del mar, que impidieron la realización del trabajo en varias ocasiones.

Efectos en el sector turístico

El turismo en la Isla Santa Cruz es fundamental para la economía de esta isla. Se han detectado efectos negativos causados por El Niño en los siguientes aspectos: el transporte terrestre, la planta física de hoteles, restaurantes y botes de turismo, y en el aprovisionamiento de combustibles. Así mismo, disminuyó el número de turistas. Además hubo incomodidad para el turista a causa del mar embravecido, la lluvia y la falta de sol. Los senderos de visita se

presentaron intransitables en diversos sitios por el aumento de la vegetación.

De los cinco vehículos que prestan servicio entre el Canal de Itabaca y Puerto Ayora, tres sufrieron daños de consideración y a dos de ellos hubo que enviarlos al continente para ser reparados. El tercero aún está dañado.

Se entrevistó a 10 de los 12 propietarios de hoteles. Cuatro de ellos reportaron daños en la planta física, consistentes en goteras y en daños de los pozos sépticos.

El turismo disminuyó de acuerdo a lo reportado por los propietarios de botes. De 21 botes que corresponden a más de la mitad de los que operan en turismo en Santa Cruz, 15 reportaron disminución entre el 30 al 70% de pasajeros. Solamente el propietario de un bote aseguró no haber tenido disminución del número de turistas. Tanto los propietarios de restaurantes como los de hoteles y de botes aseguraron haber tenido dificultad en el aprovisionamiento de víveres y de combustibles.

Efectos en la salud de la población urbana y rural

Para determinar los estragos en la salud de los pobladores se entrevistó a 100 familias del sector urbano y a 40 familias del sector rural. Las enfermedades más comunes y su incidencia en el período afectado por El Niño se muestran en la Tabla 3. Estos resultados indican que hubo alta incidencia de gripes o resfriados y de afecciones a la piel, como sarpullido, abscesos, hongos, y la aparición de vejigas de agua en la piel. Además, se presentaron trastornos gastrointestinales que se manifestaron por diarrea y vómito, especialmente en los niños. Otro malestar constituyó el dolor de oído (otitis).

Tabla 3. Enfermedades que se presentaron en la población urbana y rural en 1982-83.

Total de familias = 140

Enfermedad	No. de familias	Número de familias con			
		1-2 personas afectadas	3-4 personas afectadas	5 personas afectadas	o más personas afectadas
Gripe o resfrío	99 (71) ¹	42	43	14	
Diarrea y vómito	50 (36)	33	6	11	
Otitis	36 (26)	28	6	2	
Sarpullido	62 (44)	48	11	3	
Hongos	31 (22)	28	16	12	
Abscesos	29 (21)	22	4	3	
Vejigas de agua	29 (21)	20	5	1	

¹Porcentajes del total de familias (140) se dan en paréntesis.

Algunos de estos malestares se presentan regularmente en el "invierno" y sus víctimas comunes son los niños, quienes se ven afectados por diarrea, vómito y enfermedades de la piel. Nuestra apreciación, como moradores de la isla, es que hubo una incidencia superior a lo normal de enfermedades a la piel y de trastornos gastrointestinales en el período afectado por El Niño. Desgraciadamente carecemos de datos estadísticos de años anteriores para poder cuantificar esta observación.

Reacción de los pobladores ante el fenómeno El Niño

La manera cómo las personas reaccionaron ante los cambios que se sucedieron durante El Niño variaron de acuerdo al sitio de su residencia. Los resultados

que se reportan aquí están basados en entrevistas a 140 familias.

Las familias que viven en la parte alta de la isla se vieron afectadas por las lluvias, mas no por las marejadas. Por las lluvias fue a veces imposible bajar a la playa a vender los productos y a comprar lo que necesitaban.

En algunas fincas hay encañadas, en este caso los propietarios trataron de tomar medidas preventivas. La más eficiente fue la colocación de piedras a los lados de la encañada para evitar que se desborde e inunde la propiedad. Muy pocas personas cambiaron de domicilio hacia la parte baja. Quienes lo hicieron tenían familiares que vivían en el puerto.

Los residentes de la parte baja en general se mantuvieron informados de las noticias sobre marejadas y sobre las prohibiciones de ir al mar.

En todos los pobladores, tanto de las partes altas como de las bajas, fueron los aguaceros, vientos y truenos los que causaron temor y molestias. Por estas causas salieron menos de sus casas y trataron de protegerlas de la mejor manera. Frente a la lluvia y truenos, los moradores de la isla en general apagaron las luces de sus casas y desconectaron los aparatos eléctricos. También taparon los espejos adentro de la casa, y era típico observar que las amas de casa oraban. La gente sintió temor y una de las opiniones más comunes vertidas en la encuesta fue que sentían que "se acercaba el fin del mundo".

LAS REUNIONES DE LA FUNDACION DARWIN Y EL NIÑO

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Resumen

El artículo describe las observaciones generales sobre varios sitios del archipiélago a finales de El Niño. Estos lugares fueron visitados con motivo de la reunión número 43 del Consejo Ejecutivo de la Fundación Darwin.

Summary

The article describes the general characteristics of places in the archipelago near the end of the El Niño. These sites were visited during the 43rd Executive Council Meeting of the Charles Darwin Foundation.

Frente al trastorno climático que habían vivido las Islas Galápagos, la reunión número 43 de la Fundación Charles Darwin adquiere particular significado, pues los participantes fuimos invitados a ver los cambios que se habían operado en las Islas por efecto de El Niño. La reunión tuvo lugar el 22 de agosto de 1983 en la Estación Darwin, cuando apenas hacía poco habían cesado las lluvias fuertes. En los días anteriores y por invitación de la Compañía Metropolitana Touring, visitamos varios sitios en el archipiélago y

recibimos el trato que se da a los turistas en la M/N Santa Cruz.

He visitado las Galápagos en otras oportunidades, pero no había estado antes en varios sitios. Mi impresión de las islas por un lado me permite hacer comparaciones y por otro tiene la frescura de una primera experiencia.

Baltra siempre me impresiona; es la entrada a este mundo desolado y extraño con unos cactus y un suelo rojizo, en donde el visitante empieza a dar valor al agua dulce. Esta vez fue diferente, desde el aire la isla aparecía verde, con hierbas altas, acogedora. Frente al terminal nuevo han crecido las plantas de sandía y pude observar a unos niños que habían encontrado una y se la comían. Las cáscaras ricas aún en comida roja fueron rápidamente investigadas por pinzones con picos de varios tamaños.

Esa tarde, Bartolomé con su lava resplandeció contra un cielo brillante. Aquí y allá se veían los cactus pioneros de la lava, y desde la altura se divisó aquel paisaje de distancia, mar y soledad. Era la primera experiencia de una isla de lava joven que más parecía un paisaje lunar.

Mientras en la noche se desarrollaba una discusión sobre los temas de la reunión, el barco avanzaba hacia Isabela. Con las primeras horas del día divisé la isla y las nubes. Poco a poco los contornos se volvieron más precisos y los colores más brillantes. Grande y majestuosa apareció Isabela con sus volcanes y totalmente verde era su orilla. Hacia el otro lado, aún envuelta en bruma se divisaba a Fernandina.

Una visita en "panga" por la Caleta Tagus nos mostró a las aves posadas sobre la estratificada roca de la pared, piqueros, pingüinos y cormoranes. En un momento estuvimos debajo de la roca. Por encima de

nosotros la isla vertía agua dulce que nos mojaba. Juan Black comentó sobre sus lecturas: los piratas se aprovisionaban de agua en Tagus...tal vez la isla era más húmeda en el pasado. Más allá encontramos a una de tantas encañadas que como ríos traían agua al mar. Así se explica la impresión de verdor y de exuberancia que se sentía. La ascensión al pequeño volcán con su laguna permitió ver más de cerca a esa explosión vegetal. Todo el suelo estaba cubierto de hierbas verdes.

A la tarde visitamos Punta Espinosa en Fernandina, el mundo de las iguanas marinas, de cormoranes no voladores y de pingüinos. Inmóviles al atardecer, las iguanas marinas aparecían como un pedazo más de la lava negra. Me acerqué a una que no se movió siquiera, tal vez dormía o agonizaba. Me impresionó ver a estos dragones, tan débiles y flacos y ver los esqueletos de aquellos que no contribuirán al "pool genético" de la siguiente generación. Estos cambios ecológicos, al reducir el tamaño de las poblaciones, inciden en la evolución.

Un descanso grato de la tragedia de las iguanas y de la desolación de la lava brindaba el agua y la actividad de los habitantes. En la roca del frente varias parejas de cormoranes estaban en cortejo. Uno salió del agua y con sus movimientos lentos llegó hasta el nido portando el acostumbrado regalo de algas. Agilmente nadaban unos pingüinos y una iguana demostraba sus habilidades en el agua.

El visitante que viaja en este cómodo barco no siente las distancias que separan a un sitio de otro. Mientras cenábamos, nos reuníamos para seguir discutiendo los asuntos de la Fundación, y mientras dormíamos el barco viajó al otro extremo, a Genovesa. Durante los meses afectados por El Niño, sin embargo, también aquí se sintieron los embates. Un guía me informó que llovía y un empleado me dijo que

al suelo y se rompía, y los pasajeros sufrían mareos.

Bahía Darwin en Genovesa, donde anidan las fragatas y los piqueros, también nos recibió con explosión de verdor. El número de aves marinas, especialmente de fragatas, me pareció más bajo que en otras oportunidades. Algunos machos mostraban sus bolsa gular roja en el inicio de una nueva época de cortejamiento. Mi impresión fue de que también había un número menor de piqueros de patas rojas.

Un punto notable de la visita fue la isla Seymour Norte. Esta isla normalmente tan seca aparecía como un jardín. Unos muyuyos grandes y llenos de flores amarillas se mezclaban con otras plantas en pleno verdor. Las lianas cubrían todo el paisaje, de modo que en muchos sitios la vegetación casi llegaba a la altura de una persona a lado y lado del angosto sendero de turistas. Esta situación me pareció muy diferente con relación a mis experiencias previas. El paisaje era más despejado en mis recuerdos, con muchos nidos de piqueros de patas azules. Esta vez, unos pocos piqueros habían regresado a sus rocas para anidar. Allí, escondida entre tanta vegetación, una pareja cortejaba - extraña visión de estas aves en un mundo que se había tornado diferente. Las fragatas aquí también eran escasas.

Otra noche y otra larga travesía, esta vez hacia el sur, a Punta Suárez en Española. Aún me asombra el despertar comodamente en otro extremo del archipiélago sin haber tomado conciencia de la distancia y sin haber hecho preparativos. En mis recuerdos, sólo el llegar desde Baltra hasta Puerto Ayora llevaba unas seis horas antes de que exista la carretera, y cuando se dañó el bote casi toda la noche. Viajar así, como ahora, es más cómodo y el turista puede ver en corto tiempo mucho más de lo que yo había visto en varias visitas. El viaje más duro, largo y primitivo, sin embargo le brinda al visitante el placer de

varias visitas. El viaje más duro, largo y primitivo, sin embargo le brinda al visitante el placer de al fin llegar al punto deseado y le da más tiempo de soledad y distancia.

En Punta Suárez me sentí más tranquila, pues habían muchos piqueros que anidaban. También estaba verde la isla, pero de ninguna manera apareció como la maraña de vegetación que era Seymour Norte. Vi el elegante despegue de los albatros desde el barranco.

Al siguiente día llegamos a la Estación Darwin para la reunión formal de la Fundación. El paisaje era diferente, pues los grandes árboles de *Opuntia* y *Jasminocereus* de los alrededores de la Estación estaban completamente cubiertos por lianas. Esa noche discutí con varias personas sobre si las *Opuntias* se volvieron árboles por la presión de predación de las tortugas gigantes y de otros herbívoros, o si tal vez en otros tiempos las islas eran más húmedas y la competencia por la luz del sol determinó que las *Opuntias* crezcan.

En esta isla, cerca del Hotel Delfín, pude ver a varias *Opuntias* que se habían caído a causa del agua. Fue aquí donde noté por la primera vez que las almohadillas de las plantas caídas daban origen a nuevas plantitas. Tal vez algunas de ellas puedan sobrevivir los inviernos próximos.

El regreso a Baltra por la carretera me mostró los cambios en la misma. En Bellavista aún se veía la encañada seca. Algunas plantas han proliferado, como el pasto elefante. Otras plantas en cambio no mostraban un aspecto feliz. Al bosque de *Scalesia* en particular se le veía enfermo, con las ramas cubiertas de hojas secas y con poco verdor. El largo tramo hasta el canal mostraba plantas de tomate que fructificaban. Las *Parkinsonias* a lado y lado eran verdes y frondosas. La transición entre la vía y el bosque

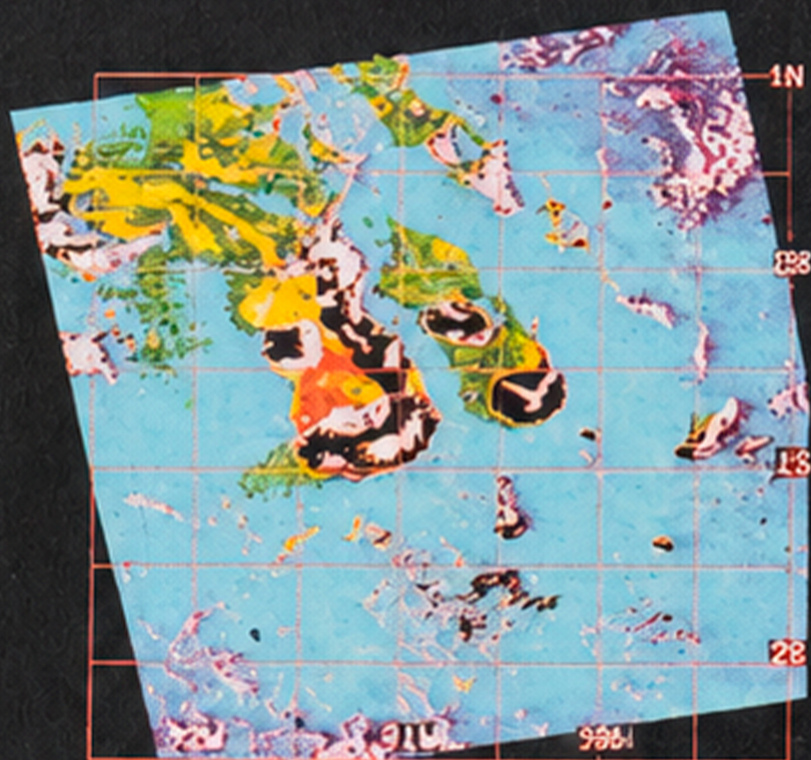
carretera permite mayor entrada de luz al suelo y así en sus márgenes pueden asentarse tantas plantas pequeñas.

En el canal mismo, un pingüino pasó junto a nuestro transporte. Unas semanas después estuve nuevamente en Baltra. En ese corto lapso el verdor se había apagado considerablemente. Como muestran los registros meteorológicos, Galápagos regresó abruptamente a su condición normal (véase el artículo por Robalino).

Como resultado del trastorno climático, ¿Cuántos cambios se habrán operado a nivel de la genética de las poblaciones en los organismos de Galápagos? ¿Cuántas nuevas introducciones de plantas y de otros organismos habrán ocurrido? Como dijo uno de los visitantes, organismos que no han sido introducidos ni por el hombre, ni por la mujer, sino por El Niño.

El Niño in the Galápagos Islands: The 1982 – 1983 event is a collection of articles written by specialists and by local inhabitants of the Galápagos Islands. El Niño events occur every year, but never with the intensity of this one. The Charles Darwin Foundation for the Galápagos Islands sponsored the collection and publication of these articles and invites scientists and planners to make use of this case history when teaching a basic conservation lesson.

The book contains five sections. The first one describes oceanographic and meteorological changes in the Islands. It gives a reference framework for the following sections. The second section is a general description of the changes and serves as introduction to the more specific sections on marine life, terrestrial life and the effects on man and his activities.



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