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Woods Hole Oceanographic Institution

Scientific Research and the Galápagos Marine Resources Reserve

**Synopsis of a Workshop
April 20-24, 1987
Guayaquil, Ecuador**

edited by

Arthur G. Gaines, Jr. and Hernán Moreano Andrade

September 1988
(1991 Reprinting)

Technical Report

Funding was provided by the Marine Policy Center of the Woods Hole Oceanographic Institution (U.S.A.)
and Oceanographic Institute of the Navy (Ecuador) with partial support
from the National Science Foundation.

English edition approved for publication; distribution unlimited.

WHOI-91-41

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Marine Resources Reserve**

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edited by

Arthur G. Gaines, Jr.
Marine Policy Center,
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts 02543

and

Hernán Moreano Andrade
Instituto Oceanográfico de la Armada del Ecuador
Guayaquil, Ecuador

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English edition approved for distribution:

James M. Broadus, Director
Marine Policy Center

Preface to 1991 Printing

This technical report reprints the proceedings of a conference held in Guayaquil, Ecuador, in 1987. The conference was a joint effort of the Instituto Oceanográfico de la Armada (INOCAR) and the Marine Policy Center of the Woods Hole Oceanographic Institution. The purpose was to explore the role of science and scientific organizations in management of the coastal and ocean assets of the then newly created Galápagos Marine Resources Reserve. Participation in the three day conference involved many Ecuadorian organizations, including some that had not previously played a conspicuous role in the Galápagos. This joint conference represented, in a sense, a capstone for our cooperative project on coastal management in the Galápagos that had begun in 1984 with support from the Tinker Foundation.

To record and disseminate the results of the conference, the collected abstracts were published in Spanish and English within a few weeks by the naval press at INOCAR. One of our purposes in reprinting the proceedings is to replenish the supply of the English version of that early conference draft, now exhausted. We have taken this opportunity to correct some typographical errors and irregularities in graphics and translation that survived the first printing. We are grateful to Ms. Theresa McKee and Ms. Sarah Repetto for their contributions in this regard.

A second purpose for reprinting these proceedings is to re-emphasize a principal conclusion—the need to incorporate high technology into the Galápagos ocean and coastal management context. Since our conference, this conclusion has taken on even greater relevance, given the advances in remote sensing, geographic information systems (GIS), satellite telemetry, and global positioning system (GPS) technology, and in their new commercial availability. Perhaps even more important have been the advances in the integration of high technology systems, such as in the Electronic Chart and Digital Information System (ECDIS) and related vessel traffic monitoring service capabilities. These technologies provide a means to monitor the environment and many kinds of human activities over vast expanses of ocean space; they provide automation and economy in place of mind-numbing and staff-intensive information collection, processing, display and storage. Equally important, this technology comes "hardened" to the rigors of marine applications, providing new levels of reliability along with the miniaturization and user friendliness increasingly characteristic of modern marine electronics. Ironically enough, such advanced technologies may be the most "appropriate" for the remote and harsh Galápagos setting.

The participation at the integrated conference underlined another conclusion we reached in an earlier report—that the basic institutional framework for integrated marine resources management in the Galápagos already exists in Ecuador. We in North America have something to contribute, but Ecuador already possesses much of what is needed to sustain the Natural Heritage of the Galápagos Island archipelago.

James M. Broadus
Arthur G. Gaines, Jr.
Woods Hole, Massachusetts

ABSTRACT

In 1986 the Government of Ecuador established the Galápagos Marine Resources Reserve encompassing the entire Galápagos Archipelago, an area embracing 70,000 square kilometers of the Pacific Ocean and its underlying seabed. A workshop, sponsored by the National Science Foundation, was held on April 20-24, 1987, in Guayaquil, Ecuador, to address the role of scientific information in planning for the management of this new Marine Reserve. The "Scientific Research and the Galápagos Marine Resources Reserve Workshop" was jointly coordinated by the Marine Policy Center of the Woods Hole Oceanographic Institution, and the Oceanographic Institute of the Navy of Ecuador (Instituto Oceanografico de la Armada).

Ten North American scholars and about thirty scholars from Ecuadorian governmental and non-governmental scientific organizations, concerned with issues related to the Galápagos, met to discuss the status of scientific information on marine areas surrounding these islands. The workshop also focused on the role this information should play in crafting a management plan that will, a) recognize and mesh with environmental realities of this complex oceanic setting, b) incorporate new scientific information as it becomes available, and c) accommodate the needs of scientists working in the remote, typically harsh and often unique setting the Archipelago provides the international academic community.

Despite some important gaps, considerable scientific information is available to Reserve managers, and examples of the use of scientific information in other marine reserves is also available. Important areas of innovation are needed in order to gather and use information effectively for the management of this vast ocean area. Remote sensing technology and international cooperation offer promise in this regard.

TABLE OF CONTENTS

PREFACE	i
ABSTRACT	iii
TABLE OF CONTENTS	iv
LIST OF ACRONYMS	ix

FORWARD

WELCOMING ADDRESS Hernan Moreano Andrade, INOCAR	1
WORKSHOP CONTEXT, GOALS, AND CONSTRAINTS Arthur Gaines, Marine Policy Center, WHOI	3
RECOMMENDATIONS	5

SCIENCE IN MARINE AREA MANAGEMENT

THE MANAGEMENT PLAN OF THE GALAPAGOS MARINE RESERVE: STATEMENT OF THE TECHNICAL COMMITTEE Fausto Cepeda, GNP, Fernando Arcos, INOCAR, Tito Rodriguez, INP, and Jose Villa, INGALA	7
THE ROLE OF SCIENCE IN COASTAL MANAGEMENT Arthur Gaines, Marine Policy Center, WHOI	12
MANAGEMENT RELATED RESEARCH AND EDUCATION PROGRAMS IN MARINE PROTECTED AREAS Nancy Foster, NOAA	19
GALAPAGOS BIBLIOGRAPHY OF SCIENTIFIC LITERATURE Arthur Gaines and Bruce Epler, Marine Policy Center, WHOI	26
THE STATE OF SCIENTIFIC KNOWLEDGE IN THE GALAPAGOS MARINE AREA	
PHYSICAL OCEANOGRAPHY:	
PHYSICAL OCEANOGRAPHY OF THE GALAPAGOS ISLANDS Vanessa Cardin, INOCAR	28

PHYSICAL OCEANOGRAPHY AND THE METEOROLOGICAL FEATURES OF THE GALAPAGOS ISLANDS Alexandra Cedenó M., INOCAR	34
VARIABILITY OF OCEANIC CONDITIONS OF THE WESTERN GALAPAGOS ISLANDS Silvia Allauca, INOCAR	40
GEOLOGICAL OCEANOGRAPHY:	
ORIGIN AND GEOLOGICAL SETTING OF THE GALAPAGOS ISLANDS Fernando Zurita F., INOCAR	46
SEDIMENTOLOGY Mitchell W. Colgan, University of California	54
BEACHES Arthur Gaines, Marine Policy Center, WHOI	57
BIOLOGICAL OCEANOGRAPHY:	
REMOTE SENSING OF PRIMARY PRODUCTIVITY: RECOMMENDATIONS FOR FUTURE REMOTE SENSING RESEARCH Steve Ackleson, Bigelow Laboratory for Ocean Sciences	59
SATELLITE REMOTE SENSING PLATFORMS FOR MARINE RESEARCH Steve Ackleson, Bigelow Laboratory for Ocean Sciences	64
THE BENTHIC MARINE ALGAL FLORA Garry Kendrick, CDRS	68
MARINE BIOTA AND HABITATS	
CHARACTERIZATION OF THE MARINE BIOTA AND PRINCIPAL HABITATS OF THE GALAPAGOS G.M. Wellington, University of Houston, and Fernando Arcos, INOCAR	72
GALAPAGOS CORAL REEFS Mitchell Colgan, University of California	81
MARINE DEPENDENT ORGANISMS Gary Robinson, Santa Barbara Museum of Natural History	85

ENDEMISM AND ALIEN SPECIES

ENDEMISM IN MARINE ORGANISMS

Gerard Wellington, University of Houston 88

INTRODUCED SPECIES AND THE GALAPAGOS MARINE RESEOURCES RESERVE

James T. Carlton, University of Oregon 92

EXPLOITATION OF RESOURCES

FISHERIES:

SOME OBSERVATIONS ON ARTISANAL COASTAL FISHERIES IN THE GALAPAGOS

Gunther Reck, CDRS 105

FISHERIES IN THE GALAPAGOS ISLANDS

Tito Rodrigues P., INP 108

TURTLES:

THE BLACK TURTLE IN THE GALAPAGOS ISLANDS

Mario Hurtado, INP 114

CORAL:

MARINE RESOURCE EXTRACTION: BLACK CORAL

Gary Robinson, Santa Barbara Museum of Natural History 118

MINERALS:

MARINE MINERALS: MISCONCEPTIONS AND MYTHOLOGIES

James M. Broadus, Marine Policy Center, WHOI 121

IMPACT OF MARINE RESOURCE EXPLOITATION ON BIOLOGICAL ECOSYSTEMS

Francisco Rada, INOCAR 127

TOURISM

TOURISM IN THE GALAPAGOS

Fausto Cepeda, GNP 129

GALAPAGOS TOURISM: THE IMPORTANCE OF INDUSTRY STRUCTURE

James M. Broadus, Marine Policy Center, WHOI 134

ENVIRONMENTAL STRESSES AND VARIABILITY

SATELLITE OBSERVATIONS OF EL NINO

Steven Ackleson, Bigelow Laboratory for Ocean Sciences 138

THE WARM SEASON OF 1987 OFF THE COAST OF ECUADOR AND ITS INFLUENCE ON THE GALAPAGOS ISLANDS

Eduardo Zambrano, INOCAR 141

VARIATIONS IN THE CONTENT OF NUTRIENTS IN THE SURFACE WATERS IN THE AREA OF THE GALAPAGOS ISLANDS

Rocio Trejos de Suescum, INOCAR 145

BIOLOGICAL EFFECTS OF EL NINO ON MARINE/MARITIME SPECIES

Gary Robinson, Santa Barbara Museum of Natural History 156

HUMAN IMPACT ON THE GALAPAGOS

IMPACT OF MAN AND HIS ENDEAVORS IN THE MARINE ENVIRONMENT OF THE GALAPAGOS

Jose Villa, INGALA 161

HUMAN INFLUENCES ON MARINE RESOURCES IN THE GALAPAGOS: EVOLUTION OF THE HUMAN PRESENCE

Fausto Cepeda, GNP 164

CHARACTERIZING THE MARINE RESOURCES RESERVE

FUTURE APPLICATIONS OF REMOTE SENSING IN THE GALAPAGOS MARINE RESOURCES RESERVE

Steven Ackleson, Bigelow Laboratory for Ocean Sciences 166

THE CENTER FOR REMOTE SENSING OF NATURAL RECOURCES' ROLE IN THE MANAGEMENT OF THE GALAPAGOS MARINE RESOURCES

Agustin Alvarez, CLIRSEN 169

GALAPAGOS PROJECTS - LOW TECHNOLOGY

Fernando Arcos, INOCAR 171

A STUDY OF THE BENTHIC FAUNA OF THE RESERVE AREA OF THE GALAPAGOS ISLANDS

Manuel Cruz, Elena Gualacanay, and Francisco Villamar, INOCAR 173

EDUCATION IN THE RESERVE AREA

EDUCATION LINKS WITH THE MARINE RESERVE

Henk Kasteleijn, and Gary Kendrick, CDRS 176

STATEMENT OF THE MINISTRY OF EDUCATION AND CULTURE

Ligia Landazuri V., Ministry of Education and Culture 178

INTERNATIONAL COOPERATION THROUGH SCIENCE

INTERNATIONAL COOPERATION THROUGH RESEARCH

H.A. Moreano, INOCAR 179

ACKNOWLEDGEMENTS

H.A. Moreano, INOCAR 181

Arthur G. Gaines, Marine Policy Center, WHOI 182

APPENDICES

APPENDIX A: MARINE RESEARCH PRIORITIES OF THE CHARLES DARWIN RESEARCH STATION

Exert from the 1987 Operational Plan 183

APPENDIX B: CAPABILITIES OF INOCAR RESEARCH VESSELS 190

LIST OF ACRONYMS

ASFA	-	Aquatic Sciences and Fisheries Abstract
AVHRR	-	Advanced Very High Resolution Radiometer
CDRS	-	Charles Darwin Research Station, Ecuador
CLIRSEN	-	Center for the Remote Sensing of Natural Resources, Ecuador
CONADE	-	National Development Council, Ecuador
CPE	-	Catch Per Unit Effort
CPPS	-	Permanent Commission of the South Pacific
CZCS	-	Coastal Zone Color Scanners
CZM	-	Coastal Zone Management
DCP	-	Data Collecting Platform
DIGEIM	-	National Directorate of Maritime Interests, Ecuador
DIGEMA	-	National Directorate of the Environment, Ecuador
EMC	-	External/Environmental Marginal Cost
ENSO	-	El Nino - Southern Oscillation
ERFEM	-	Regional Study of the El Nino Phenomenon
GMRR	-	Galápagos Marine Resources Reserve
GNP	-	Galápagos National Park
GOFS	-	Global Ocean Flux Study
IATTC	-	Inter-American Tropical Tuna Commission
INAMHI	-	National Institute of Meteorology and Hydrology, Ecuador
INGALA	-	Galápagos National Institute
INOCAR	-	Oceanographic Institute of the Ecuadorian Navy
INP	-	National Fisheries Institute of Ecuador
IUCN	-	International Union for the Conservation of Nature
MICIP	-	Ministry of Industry, Commerce, Integration and Fisheries of Ecuador
MPA	-	Marine Protected Area
MPS	-	Marine Polymetallic Sulphide
MSS	-	Multispectral Scanner
MYA	-	Million Years Ago
NMS	-	National Marine Sanctuaries
NOAA	-	National Oceanic and Atmospheric Association
NROSS	-	Navy Remote Ocean Sensing System
NSCAT	-	Microwave Scatterometer
OCI	-	Ocean Color Imager
PNG	-	Galápagos National Park
SCOR	-	Scientific Community for Oceanographic Research
SSEW	-	Subsuperficial Equatorial Water
SST	-	Sea Surface Temperature
STW	-	Surface Tropical Water
TM	-	Thematic Mapper
TOGO	-	Tropical Ocean and Global Atmosphere
WHOI	-	Woods Hole Oceanographic Institution

FOREWORD

Welcome Address

**Lt. Cdr. Hernan Moreano Andrade, Director
Oceanographic Institute of the Navy
Ecuador**

It is a pleasure for me to address you this morning; and, on behalf of both the Woods Hole Oceanographic Institution (WHOI) and the Oceanographic Institute of the Navy (INOCAR) I welcome everyone to this Workshop on the Galápagos Marine Resources Reserve, which, under the sponsorship of both institutions, will take place in this auditorium during the next four days.

Problems of coexistence between man and the land and nature of the Galápagos Islands are complex enough to cause constant concern, to the point that an International Botanic Workshop met a few days ago in order to establish future guidelines and patterns for the management of the Galápagos National Park. Coexistence of man and the Marine Reserve area is as, or more, complex than that on the islands. This explains the interest of WHOI and INOCAR in conducting this workshop as a joint effort, along with valuable participation from other Ecuadorian government institutions who are involved in a wide variety of activities in the Archipelago.

The Workshop will support deliberations of the Technical Committee, established by the Inter-institutional Commission for the management of the Marine Reserve, in the analysis of scientific knowledge on the following subjects:

- o Geological, biological and physical oceanography in the Galápagos Islands;
- o Distribution of primary productivity and marine organisms in Galápagos waters;
- o The impact of urban zones on the marine areas;
- o The biological, mineral, tourist-related, scientific and technological resources of the Galápagos and their requirements for management, and;
- o International cooperation through research in the specific case of the Archipelago.

The purpose of these efforts is to provide the Technical Committee with the information they will need in order to establish a basis for the Marine Reserve Management Plan.

I am confident that the highly qualified participants in the Workshop will help to define a wide

spectrum of criteria, and that the conclusions drawn from them will greatly benefit and expedite the job that the Technical Committee is performing.

Finally, I wish to express the great pleasure that we, as members of INOCAR, feel in having you as our special guests. I greatly hope that the talks and discussions of these next few days will produce fruitful results for the benefit of the Archipelago and, of course, for our country.

Workshop Context, Goals and Constraints

Dr. Arthur G. Gaines
Marine Policy Center
Woods Hole Oceanographic Institution
U.S.A.

With his 1986 decree establishing a Galápagos Marine Resources Reserve area (Fig 1) the President of Ecuador has taken an important step toward protecting the unique natural features of the Galápagos. With this action the President responds to a truly unprecedented national and international appeal of increasing pitch over 1 ½ centuries since the island's unusual biota was first revealed to the world.

For purposes of delineating a management process for the marine area, the decree also created an "Inter-Institutional Commission" to enlist the energy and expertise of seven Ecuadorian agencies. The "working arm" of the Commission is a five member Technical Committee that holds the responsibility of crafting a pragmatic plan from the aspirations and abstractions of those whose dreams may not always be practical.

The Technical Committee consists of:

Sr. Fausto Cepeda (Chairman), Galápagos National Park (PNG)
Sr. Fernando Arcos, Oceanographic Institute of the Navy (INOCAR)
Sr. Tito Rodriguez, National Fisheries Institute (INP)
Sr. Jose Villa, Galápagos National Institute (INGALA)
Ab. Efrain Perez (Consultant)

It is our special objective to aid this group in their difficult work.

The Galápagos Marine Resources Workshop originated from a cooperative program between the Marine Policy Center at Woods Hole and the Government of Ecuador, beginning in 1983. The workshop has been jointly planned and hosted by our Center and the Oceanographic Institute of the Ecuadorian Navy; and I am grateful to Captain Hernan Moreano A., Director of INOCAR, for his guidance and help and ongoing attention.

The process of formulating a workable management plan will ultimately involve several different disciplines: law; economics; public administration and others. Our central objective in the workshop is to address only one of these - the place and role of scientific research.

From the composition of the Inter-Institutional Commission and its Technical Committee, it is clear that the importance of science is recognized at the highest levels of the Ecuadorian Government.

An important condition attached to this workshop is that its results be useful to the Technical Committee. This means among other things that the results be provided quickly and in Spanish. I am grateful to all of the workshop participants for accepting the inevitable compromise this urgency places on editorial quality of the manuscripts. I hope critics of the Conference Draft can appreciate the larger purpose we are attempting to serve.

Figure 1. Map of the Galápagos Marine Resources Reserve.

Recommendations

1. Science should influence the framework of the Galápagos Marine Resources Reserve management plan in two distinct ways:

- a) Scientific information and methodologies should serve as the basis for characterizing and understanding the natural and cultural systems addressed by management.
- b) Reserve management strategies should accommodate the needs of Ecuadorian and foreign scientists and scientific organizations for conducting future basic and applied research.

2. National and international scientific cooperation should be promoted as a means to fund and carry out the large number of research, survey, and monitoring studies needed for proper management of the Reserve. The great international appeal for funding of science in the Galápagos Archipelago stems from the union of:

- a) Unusual natural features and research opportunities of the setting.
- b) The history of and future prospects for international collaboration.
- c) Ecuador's rededication to conservation of natural systems in the Galápagos for science, education and low impact use over the long term.

3. Because of the great size and complexity of the Marine Resources Reserve, remote sensing techniques should be used fully to define the environment, its resources and habitats, human impacts, and El Niño variability. More specifically:

- a) Existing imagery should be obtained and made available to Ecuadorian scientists.
- b) Officials at the highest levels in the U.S. and Ecuador should be urged to support the exchange of state-of-the-art remote sensing technology, methodologies and products.
- c) New, large scale aerial photographs (color stereo pairs) of the entire Galápagos coast, needed for many purposes in managing the Reserve, should be obtained by Ecuadorian agencies using existing facilities and expertise.

4. Public participation should be encouraged to help set goals and priorities for management of the Reserve. An enhanced sense of stewardship should be instilled in all Ecuadorians with regard to the Galápagos Archipelago.

5. The focus of these recommendations - - science and technology - - is only one aspect of management formulation. The Government of Ecuador should support the future efforts of the Inter-Institutional Commission and its technical and advisory committees in addressing other management components for the Marine Resources Reserve.

**The Management Plan of the Galápagos Marine Reserve:
Statement of the Technical Committee**

Fausto Cepeda
Galápagos National Park, Ecuador

Fernando Arcos
Oceanographic Institute of the Navy, Ecuador

Tito Rodriguez
National Fisheries Institute, Ecuador

Jose Villa
Galápagos National Institute, Ecuador

Introduction

Because of the Galápagos uniqueness and because of the relationship that exists in these islands between the marine and the terrestrial resources, the Ecuadorian Head of State proposes to protect and conserve the marine and coastal resources of Galápagos islands under a single management process.

The joint report of the Forestry Directorate and the Charles Darwin Scientific Station, "Criteria for the Declaration of the Marine Reserve", was the immediate antecedent to the declaration of the marine reserve, through Executive Decree No. 1810-A. This report was the culmination of several studies, among which the following can be mentioned: "Coastal Environment of the Galápagos" submitted in 1975 by G. Wellington to the Department of National Parks; the seminar for the inclusion of the Galápagos marine area to the National Park, held in San Cristobal, Galápagos in 1978; and the Revision of the Proposal for the Incorporation of the Marine Area to the Galápagos National Park, in 1981, with participation of The Galápagos National Institute (INGALA), Under-Secretary of Fisheries, Charles Darwin Scientific Station, and the Galápagos Forest District.

Terms of Reference

The Galápagos Marine Reserve was created by Executive Decree 1810-A of 29 April, 1986, with a mandate to design a management plan within a 365 day period. Actual work on the plan was delayed until January 1987, due mainly to the complexities of the project and the need for international assistance. The National Forestry Directorate obtained an extension of the term for the delivery of the plan to December 31, 1987.

The following institutions were invited to serve as advisors:

1. The Woods Hole Oceanographic Institution (Marine Policy Center);
2. University of Rhode Island;
3. The Australian Great Barrier Reef Marine Park Authority, and;
4. The U.S. National Oceanic and Atmospheric Administration.

Three commissions were structured in order to formulate the Management Plan:

Inter-Institutional Commission, consisting of several ministries and agencies:

-Ministry of National Defense
National Directorate of Maritime Interests
[Rear-Admiral Alfonso Pinto T.] DIGEIM

-Ministry of Foreign Relation
Directorate of National Sovereignty
(Dr. Ruben Ribadeneira).

-Ministry of Agriculture and Livestock
National Directorate of Fisheries
(Ing. Mario Pescarolo).

-Ministry of Industry, Commerce, Integration and Fisheries
(MICIP) Under-Secretary of Fisheries.

-Ministry of Energy and Mines
National Directorate of the Environment (DIGEMA).

-National Development Council (CONADE).

-Presidence of the Nation - Galápagos National Institute
(INGALA) [Arq. Abdon Guerrero].

The Technical Committee

Composed of Ecuadorian experts whose duty is to design the management plan within a six month span. Members of this group are:

Msc. Fernando Arcos -INOCAR
Lcdo. Fausto Cepeda -PNG
Biol. Tito Rodriguez -INP
Msc. Jose L. Villa -INGALA

An International Commission

Whose members are the foreign institutions forenamed, with the assigned purpose of advising the technical committee.

The Management Plan was not conceived of as involving primary research; instead it was to develop from a bibliographic analysis to cover at least the following areas:

1. Description of the general characteristics of the marine area of the Galápagos;
2. Actual and potential human uses of the region;
3. Legislative and institutional aspects;
4. Targeting of the kind of agency that should take charge of the management of the area;
5. Establishment of the operative guidelines for the gradual implementation of the plan.

Some of our early considerations in these task areas follows.

Description of the General Characteristics of the Marine Area

The overall area of the marine reserve is about 70,000 km². Its coastline is longer than 1,400 kms. The circulation of the waters is very active in the oceanic region, such that natural flushing occurs in the system.

In order to understand the coastal and marine environment of the islands, several areas of study should be assessed by the participants of the Workshop.

Some of these that we have already identified are:

-Geographical setting of the islands
and the marine area within the Equatorial
Eastern Pacific	-Characteristics of the marine ecosystem
-Geomorphology of the littoral zone	-Major Coastal and Marine Habitats
-Oceanic circulation	Mangroves
-Interior currents	Rocky coasts
-Temperature	Sandy beaches and bottoms
-Salinity	Coral and coral reefs
-Oxygen	Rocky bottoms of lava
-Nutrients	Vertical walls
-Climate	Rocky bottoms
-Tides	Tuffaceous bottoms
-Ecological and biogeographical
consequences of the hydrography	Salients
-Zoogeographical affinities	Large submarine rocks
-Systems of dispersion	Submarine rocks
-Barriers	Sea tunnels and caves
-Primary productivity	Submerged mounts
-Secondary productivity	Neritic pelagic environment
-Characteristics of the marine environment	Oceanic pelagic environment

Information included in these categories is being compiled from the scientific literature, and through consultation with experts and persons knowledgeable in the different matters above mentioned.

Actual and Potential Human Uses

Tourism

Most of the present Galápagos tourist attractions fall within the terrestrial area, which is under the jurisdiction of the National Park. However, we have to analyze marine tourism and especially its potential. In order to reach the island visitor sites, it is necessary to navigate in the sea. Furthermore, in the vicinity of these sites, a number of recreational activities involve use of the sea (e.g. snorkeling). Increasingly, cruises are organized with the exclusive purpose of catering to diving vacations, which are sustained by the extraordinary attractiveness of the coastal and marine areas.

Transportation

The marine areas of the Galápagos are used for transportation, be it inter-island or island-continent transport. Therefore, it is important to monitor methods of cargo and passenger conveyance. Growth of the transportation industry in the region is liable to increase human impacts upon natural resources due to the disposal of refuse, and the increased accessibility of the area in terms of resource extraction.

Fisheries

At present, it is possible to say that there are three kinds of fisheries in the Galápagos islands:

- a. Artisanal fisheries - mostly involving species of the family Serranidae and other demersal species, such as mullet;
- b. Semi-industrial fisheries - primarily involving two commercially important species of lobster;
- c. Industrial fisheries - including Ecuadorian and foreign tuna fleets. Japanese fisheries are believed to work in association with Ecuadorian companies.

Regulations have been proposed that offer some alternatives to the Galápagos fisheries management, namely, the management of lobster and cod fish and demersal species.

Two different log books have been developed to record catch statistics: one for cod fisheries and another for those vessels that use long-lines.

Legal and Institutional Issues

The creation of the marine reserve and the development of a management plan are historical occurrences that underline the need for a specific legal and institutional framework especially fashioned to accommodate the uniqueness of the Galápagos. We anticipate that many of the laws and institutions applicable to management of reserves on continental Ecuador will be inappropriate for the Galápagos. An understanding of the institutional and legal framework required will evolve as we analyze resources and their anticipated uses in the Marine Reserve.

The fulfillment of such an objective is an arduous task; it requires a wide consensus amongst the different participants through a medium term process.

Operative Directives for Gradual Application

The mere creation of the Marine Reserve, covering an enormous, complex and dynamic environmental area, necessitates gradual implementation of a management plan. The key to success will be in the formulation of a skeleton plan in which details can be incorporated as we continue to refine the principles and goals for the Reserve.

Science in Coastal and Marine Area Management: The Role of Science in Coastal Management

Arthur G. Gaines
Marine Policy Center
Woods Hole Oceanographic Institution
U.S.A.

The Galápagos Marine Resources Reserve area encompasses an ocean island complex described by a surprising diversity of scientific disciplines as "unique", "extraordinary", and "remarkable". The task of designing a management infrastructure that permits conscious and informed choices among use alternatives, while avoiding unexpected side effects, is a challenge deserving of the maximum national and international support possible.

We believe science can play two essential and separate, though interrelated, parts in the formulation of the management process: a) science provides the means for describing the natural features and processes of the archipelago, such that management can mesh with the realities of the natural system; and, b) the needs of the international scientific community for conducting future research (and providing ongoing refinements in this management) must be accommodated in structuring the management system. If science is incorporated in both these ways, we feel that sustainable products of the Marine Reserve will result. These include: low impact tourism and other island-based economies; international cooperation and goodwill for Ecuador; and natural history education to enrich the lives not only of Ecuadorians but of all humanity into the distant future (Fig. 1).

Figure 1. Products of proper management of the Galápagos Marine Resources Area.

Typically, the management process starts with identifying principal issues by assessing the realities of the physical and human condition in light of a suite of cultural and political goals, objectives and priorities (tempered, of course, by many constraints). At the broadest scale Ecuadorian national policy goals for management of the Galápagos Archipelago appear quite clear: a) retention of clear sovereignty; b) strict conservation of the biota and the environment on which it depends, and c) promotion of the social well-being of the human population (Fig. 2).

Figure 2. National goals for management of the Galápagos Archipelago.

In principle, the process of identifying and addressing issues will remain imperfect until the scientific basis for recognizing and articulating the realities is in place. In practice, management would probably proceed even without science, but it is our contention that management failure is inevitable under these circumstances.

In the remainder of this paper I hope to put into better perspective the place of science in coastal and marine management by outlining the North American experience. This discussion uses the framework of Robert Knecht (undated), credited with implementing the U.S. Coastal Zone Management Act of 1972. Knecht was a Senior Fellow at the WHOI Marine Policy Center for 2 years. On the basis of studies of over 30 coastal management programs in the U.S. three elements appear essential:

- A. Problem definition
- B. Policy formulation
- C. Implementation approaches

Table 1. Management Issues for a Galápagos Coastal Zone Management (CZM) Program
(modified from Broadus et al., 1984)

<i>Introduction of exotic species</i>
Intentional introduction of agricultural and domestic species
Unintentional introductions
Agriculture associated
Shipping
Airplanes
<i>Chemical Contamination</i>
Natural contamination
Seawater contamination of coastal groundwater
Man-induced
Intentional Activities
Sewage disposal
Contaminating groundwater
Contaminating harbors and coastal waters
Dumps and rubbish disposal
Agricultural chemicals
Fertilizers
Pesticides
Herbicides
Burning
Accidental
Oil spills
Cargo loss in shipwrecks or vehicular accidents
<i>Resource Extraction</i>
Beach sand quarrying
Volcanic aggregate quarrying
Salt mining
Industrial fishing
<i>Natural hazards</i>
Volcanism
Flooding
Fire
Beach erosion
<i>Esthetic sensitivities</i>
Urban design and development
(e.g., architectural design, uniformity, and choice of materials)
Agricultural infrastructure and practices
(e.g., handling of livestock, slaughter practices)
<i>Facilitation of water-dependent development</i>
Port and harbor-related
Fisheries-related
Tourism/visitor-related
Recreation-related
Siting of industrial facilities
(i.e., power generation, sewage treatment plants).

Problem definition itself involves four categories of problems:

Substantive problems are those to be addressed by the management program. For the Galápagos Marine Resources Reserve, these might include introduction of alien species; fisheries development; chemical contamination; resource extraction; aesthetic sensitivities; and natural hazards mitigation. Table 1 gives other examples.

Other categories of problem definition address structuring and operation of the management program itself. *Institutional/Legal* problems often include lack of needed authority for the management program, or inadequate laws or enforcement abilities. *Technical* problems associated with a program could be lack of data, understanding or staff. *Economic* problems are virtually ubiquitous and place constraints on the scope and scale of program activities.

Policy formulation entails elucidation of general guidelines on how the above problems and opportunities are to be addressed. In North American management programs, policy formulation can be grouped as follows:

- Coastal area use
- Marine resource use
- Natural system protection
- Intergovernmental coordination

Coastal area use policies are concerned with how activities at the border of land and sea can be guided to minimize adverse impacts on both the environment and the human population. In the Galápagos, these policies might address the siting of buildings, port and harbor design, and natural hazards such as El Niño flooding. Accommodation of tourist needs in urban areas also falls into this category.

Marine Resource Development policies guide activities such as fisheries development, mineral extraction, or ship-based tourism practices.

Natural systems protection policies in coastal areas is a field in which the Galápagos National Park (in cooperation with the Charles Darwin Research Station) has already made a strong start and may lead the world. For the newly created Marine Resources Reserve area, protection policy will have to address a complex, unusual environment in which neither the organisms nor the environment is yet well understood.

Intergovernmental coordination policy guidelines have been of critical importance for North American programs, many of which were formed by networking pre-existing coastal related agencies. This may be of significance for the Galápagos as well. Broadus and Gaines (1987) concluded, in part, "The basic elements of a Coastal Zone Management and Marine Resources Management system are already in place in the Galápagos, but they are uncoordinated and

largely ad hoc in nature." Thus, effective coordination among the Galápagos National Park; the Galápagos National Institute (INGALA); the Oceanographic Institute of the Navy (INOCAR); CONADE; The National Fisheries Institute; the Center for Remote Sensing of Natural Resources (CLIRSEN) and many other agencies with coastal planning, enforcement, research and regulatory mandates could in itself contribute significantly to a management infrastructure for the Marine Resources Reserve Area. In fact, we see important progress in this area already, of which this workshop may be an example.

Implementation policies are needed to achieve the goals developed in response to delineated marine area problems and opportunities. Commonly, implementation policies apply a range of mechanisms to promote compliance, such as :

- Laws and regulations
- Guidelines or standards
- Tax relief
- Technical assistance
- Loans and grants

Organization of Science

What kinds of studies will be most likely to aid management of the new Marine Resources Reserve? The answer is not simple because it is the very nature of science that advances come in unexpected areas of research. "Applied" studies that promise immediately useful results may not stand rigorous scrutiny, or may be so case-specific that they are of little use outside their immediate context. More basic research is expensive and often appears to have no practical use to those who are asked to pay the bill. Yet if the same standards were applied to medical science humanity would have suffered. Table 2 identifies some management-related problem areas. Many of these problem areas in fact contain more basic scientific questions, such as many of the research projects identified by this workshop.

Academic disciplines can be arranged in a hierarchy in which the levels of organization form a continuum (Table 3). According to this scheme any level of study can be viewed as integrating the next lower level or as becoming an element in the system described by the next higher level. For example, organisms can be viewed as elements in a population, populations as elements in a community and communities as elements of ecosystems. Many scientists believe that ultimately this relationship will allow understanding of complex systems in terms of the properties of their constituent parts. However, other scientists argue that some properties of complex systems, such as ecosystems, can never be predicted from knowledge of their constituents alone. In any case, it is often cheaper and easier to describe a complex phenomenon than to derive this from information about its parts. Therefore, while information from any level of scientific study could be useful, it is clear for management, that research in many disciplines in the hierarchy of science is appropriate.

Table 2. High Priority Concerns Surrounding the management of the Galápagos Islands
(from Knecht et al., 1985)

Major Concerns

Cross-Cutting

- Population Growth
- Endemic Species Protection
- Human Impact on the Environment
- Tourism Development
- Self-Sufficiency
- Government Structure, Process, and Services

Artisanal Development

- Agricultural Production
- Fisheries Production
- Island Business and Crafts

Science and Nature Education

- Scientific Research
- Nature Education

B. Selected High-Priority Study Areas for the Galápagos Islands

Short-Term projects

- Human Population Dynamics and Demographics
- Tourism
- Marine Reserve Area
- Municipal Solid Waste Management Options
- Self-Sufficiency & Appropriate Technology Scenarios
- Municipal Zoning Codes
- Standard of Living, Public Health and Welfare

Long-Term projects

- Endemic Species Protection
 - Urban Area and Special Use Zone Environmental Impacts
 - Inventory Mapping
 - Environmental Education Development
-

An examination of the focus of research in just three research organizations concerned with the Galápagos Islands suggests quite a different focus in the disciplines studied (Table 3). For example, INOCAR is the principal Ecuadorian oceanographic institute and the only one that operates a modern oceanographic research vessel. Interests at INOCAR range from global or ocean scale research to studies of benthic or planktonic communities. The National Institution of Fisheries (INP) has a somewhat different focus of research, ranging over a smaller geographic scale and emphasizing, naturally, fisheries studies. The Charles Darwin Research Station (CDRS) focuses more specifically on the Galápagos archipelago, and is associated with more specialized studies. Perhaps more than the others, CDRS is free to encourage purely basic research as well as management related applied programs.

Table 3. A Hierarchy of Scientific Research

Together, these three groups can embrace a range of research from basic research on organisms through global scale research (such as on El Niño), all of which can be important to managing the Marine Resources Reserve. It is the breadth and depth of organizations interested in the Galápagos that makes the research possibilities in the archipelago of special interest and of particularly strong promise for international funding of collaborative research.

References

Broadus J.M. and A.G. Gaines, 1987. Coastal and Marine Area Management in the Galápagos Islands. Coastal Management Vol. 15: 75-88.

Knecht, R.W. (undated). Policy Issues for Coastal Area Development/Management: Legislature, Agencies, Programs. Office of Coastal Zone Management, Washington, D. C. 8pp.

Management Related Research and Education Programs in Marine Protected Areas

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A solidly based research program plays a key role in the management and day-to-day operation of marine protected areas (MPAs).

Examples are:

- Determining appropriate boundaries
- Planning for future use and development of the area
- Monitoring and predicting changes in populations and habitats.
- Predicting impacts of regulations on resources and uses.
- Assessing the effectiveness of regulations.
- Interpreting resources values and activities directly and indirectly affecting those values.
- Assessing use of resources in a manner compatible with conservation.

To meet these requirements, research carried out in marine protected areas must address real management concerns. Research products must be designed for use by managers and the overall research program must cost-effectively contribute to on-site operations in the short and long term.

I would like to outline the nature of management-related research and explain its role in interpretation, resource protection, and enforcement. Examples will be given of research products that have been used for management in marine protected areas worldwide. Low cost interpretive projects based on research and focused on conservation issues are also covered.

Elements of a Fully Operational Marine Protected Area (MPA)

Before discussing management-related research, it helps to review the elements of an MPA plan. It is not uncommon to find that senior administrators, politicians, scientists, and the public do not necessarily understand the physical and institutional dimensions of marine protected areas nor their management components.

Many often assume that MPAs are the equivalent of terrestrial national parks on water, for example. In fact, marine protected areas differ greatly from parks on land and those differences

influence not only the kind of research needed but also the overall management program.

Marine protected areas vary considerably worldwide in their objectives, the resources being protected, and their institutional arrangements. The U.S. network of National Marine Sanctuaries (NMS), for example, includes small and large coral reefs in Florida, very extensive cold-water sites in California, and even a shipwreck of historical significance - the Monitor National Marine Sanctuary.

Worldwide, marine protected areas range from extensive multiple use areas such as the Great Barrier Reef to a variety of special purpose sites such as New Zealand's fisheries reserves, scientific reserves in the Mediterranean, and recreational marine parks in the Caribbean.

Despite these differences, there is general agreement that certain elements or activities have to be in place for an ideal marine protected area to be fully operational.

A management plan should generally include the following components:

- o **Goals and Objectives.**

You must have a clear idea of the reasons for designation of the MPA and what you are trying to accomplish. The entire plan is then focused on those goals.

- o **Setting.**

Most plans contain a brief description of the areas resources including human resources and uses. If your plan is to be used as a public relations document and/or in fund raising efforts (both within and outside government) this section offers an opportunity to show the special nature of the area.

- o **Administration/Operation.**

Most people want to know how the MPA will be managed on the ground. Describe its plan in the government hierarchy, legal foundation, planned personnel, surveillance and enforcement (if any), visitor facilities and projected funding levels or sources in general terms.

- o **Research Component.**

This is one of the most important sections of the plan. It generally identifies two types of informational needs -- the longer term needs (usually more expensive) such as inventories, monitoring, etc., and those special projects assigned to meet more immediate management needs. The latter will usually be the priority projects funded with MPA funds (assuming there are any). The former will be those for which you devise ways to entice scientists to work in the MPA and bring their own funding. Examples: offer assistance in collecting or logistical support; provide space or boat use; attract a graduate student with minimal funding -- they work hard, are extremely productive, are likely to return though the years with their own funding and might bring their major professors along.

There are three target levels for research results:

- scientific community
- the manager
- the general public

Research results are a powerful interpretive tool and should be factored into the next component of the management plan.

o Interpretive Component.

You must know the message to be imparted and the audiences to be targeted. It is no longer adequate to teach general marine biology; but rather the focus must be on conservation issues. MPAs must communicate understanding the area, why the resources need special protection, how they can help and how to use the resources wisely while fulfilling conservation.

o Resource Management Component.

This section, includes regulations (if any), do's and don'ts and emergency response (if relevant).

Role of Research in Management - Some Examples

Research can play an important role in all the elements of management outlined above. In fact, in developing the research program for a marine reserve, it helps to anticipate how results will be used in operations.

The following are examples of research in U.S. MPAs that have been used in this way:

o Resource Inventory.

A generic look at resources in the Looe Key area was extremely useful to management prior to designation. During development of the proposal it allowed boundary determination and zoning regarding special resources and user conflicts;

o Evaluation of the effectiveness of a protective regulation: a study of the recovery of a predator fish population following the ban of spearfishing at Looe Key NMS. A management application of the study that:

- designed of other regulations
- illustrated the value of some selected regulations to various user groups
- justified the program (research can produce evidence that the MPA does make a difference).

Note that the evidence provided by research becomes very effective material for on-site interpretation for the public and school groups.

o **Damage Assessment and Resource Recovery:** The Wellwood freighter (400 ft.) destroyed a large portion of Molasses reef in the Key Largo National Marine Sanctuary when it carelessly grounded. In order to pursue an effective damage claim and collect penalties we asked scientist to design a damage assessment and studies to assess recovery rates. Based on their work over a 2 1/2 year period the owners settled, resulting in almost seven million dollars being paid to the U.S.

o **Underwater interpretation.** Using special video equipment a diver demonstrates research being carried out underwater. The equipment is expensive but the Program was able to obtain it by means of a donation from an offshore oil company;

o **Changing attitudes - Entanglement studies.** Anecdotal evidence has indicated for years that marine debris poses a serious threat to marine animals. In the beginning, however, the issue appeared to be based primarily on emotion. Sources of hard data were lacking. The scientific community was approached for documentation of the problem; identification of sources; and impacts of non - biodegradable plastics; and developing effective means of control. The shift from the emotional to the scientific approach has brought credibility to concern over this issue. That, combined with a tie to economic safety impacts, has shifted public concern and brought the problem to the attention of governments worldwide, thereby increasing the chances of a solution.

o **Integrating Traditional uses into Management -** Research on Northern fur seal population declines and subsistence use has led to establishment of native harvest levels on an annual basis. Anthropological research in American Samoa led to integration of traditional life styles into management of Fagatele Bay National Marine Sanctuary.

o **Habitat mitigation** through the restoration and enhancement of damaged habitat and generation of new replacement habitats are methodologies recommended by permitting agencies to ameliorate losses of submerged and emergent wetlands and subtidal shallow-water habitats critical to the growth and survival of living marine resources. Although mitigation procedures may be an effective strategy for reducing the rate of habitat loss, present information on mitigation practices does not adequately quantify the extent to which approaches are most successful or whether habitat mitigation adequately compensates for the loss of natural habitat. The science of mitigation is still untested and imperfect, and there is little basis upon which to judge whether mitigated habitats (which may take many years to develop, if they do at all) support estuarine production to an extent similar to natural habitats. The Federal and State agencies which have recommended mitigation as part of the permitting procedure simply have not evaluated the consequences of their recommendations, either in terms of success or failure. This is a perfect place for science to help us resolve this dilemma.

What has been the success of historic attempts to mitigate and/or enhance estuarine habitats? How do the functional values of rehabilitation compare to natural habitat in terms of productivity of living marine resources; how long does it take to regain the functional values of natural habitats through mitigation and enhancement; and what is the interim living marine resource loss?

Low-Cost Marine Interpretation Programs For MPAs

The NOAA Protected Species, National Marine Sanctuaries and Habitat Conservation programs are not large budget operations. In fact, we often have to operate like a low-budget operation under serious financial constraints.

Because of the funding situation, the Office has had to be creative about how to obtain funds and use funds for marine interpretation. As everyone knows brochures, interpretive displays, etc., are expensive.

Low Cost Interpreting Projects Used in MPA's Worldwide

A cautionary note. An effective interpretive program must be more than a list of projects. It must be organized around a central message(s) or theme and objectives with projects targeted to certain audiences. The following is a list of projects that have been successfully used in MPA's around the world:

- o Establish Foundation or Cooperating Associations to raise money for on-site activities and interpreting materials such as brochures, school curricula, posters, etc.
- o Train and use volunteers for on-site interpretation;
- o Develop cooperative programs with universities and research institutions. Set up free lecture series aimed at local residents and/or tourists at schools, hotels or churches. Most professors and scientists will donate at least one lecture.
- o Prepare a catalog of needs (i.e. materials \$ 50.00; computer, \$2,000; mooring buoy, \$1,000, etc). Circulate to foundations, corporations and individuals likely to contribute.
- o Share interpretive facilities with other agencies and institutions; place material in hotels, on local airlines, tourist sites, post office, etc.
- o Sponsor photography contest in the MPA - get local merchants to donate a prize, the reserve gets the photos for use in interpretive displays and the public gets involved.
- o Ask local newspapers to donate occasional free printing.
- o Prepare topic or current issue one page handout; type and xerox.
- o Offer a workshop specifically for political and public administration decision-makers; Use reserve staff volunteers and scientists willing to donate a day of their time.
- o Work MPA conservation/management messages through established youth organizations

(church groups, scouts). Go to them or bring them out for day long or week-end retreats. Use volunteers. Develop a research oriented interpretive project. Show them "real research".

- o Put posters - focused on MPA - on public buses and trains.
- o Work with teachers and schools to sponsor a science fair; focus projects on MPA resources and issues; encourage parents to help; open exhibition of projects to local community.

My final point is perhaps most important of all: successful management plans cannot be prepared by disinterested outside consultants, although special skills brought in from the outside can provide important assistance. The people and the government institutions who will work with the plan on a daily basis and who must defend it in the long term should be central in the formulation process.

Discussion

Role of Public Participation

The level of public participation in the planning and operation of the MPA varies from country to country. In the U.S. it is extensive and begins with the earliest phases of the project. The value of local involvement early in the process can't be overemphasized:

- o It gives the planner a chance to explain the project and how it might affect the local community;
- o It gives the community a chance for early input, therefore avoiding surprises later;
- o It gives the community a sense of having a stake in the MPA and is more likely to result in future support and involvement on their part. Their involvement can be brought about through a number of mechanisms:
 1. Local meetings, where the project is explained and people are made to understand what it will mean to them (positive educational benefits, a role in an advisory capacity, restrictions).
 2. Meetings with local leaders rather than general meetings. Put leaders in an advisory capacity and let them communicate with their people.
 3. Meet with leaders of individual users, i.e. fishing community, tourist industry, school teachers, etc.

In each of the above either go prepared to explain how you should like them to participate or ask the question of them. They should be made to feel a part of the project, not as being informed of decisions already made.

Commentary

James Broadus: Nancy Foster has presented an outline of the parts a management plan might have. For the Galápagos much of the materials for these sections already exist in documents. For example, goals and objectives are found in the Presidential Decree, Forestry Law (Biological Reserves), Plan Maestro Galápagos, Galápagos National Park law, and elsewhere.

Information on the Galápagos setting exists in many of the papers in this report, in statements of the Charles Darwin Research Station and elsewhere.

Arthur Gaines: Dr. Foster's presentation is a wonderful display of practical thinking, and the record of her program stands as a measure of her success. I would caution, however, that the push for direct management related research should not become an obstacle to scholarly, curiosity-driven research. This is particularly important for the Galápagos where a principal objective is to preserve natural systems for research.

Galápagos Bibliography of Scientific Literature

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A large number of scientific publications discuss studies conducted in the Galápagos Islands. According to the Charles Darwin Research Station about 20,000 references exist, many of which are cited in an unpublished bibliography produced by the Smithsonian Institution. This bibliography is complete through 1978 when it was terminated.

Figure 1 (from data of Simkin, personal communication) gives the chronology of report publication, showing the rapid growth in research corresponding to the formation of the Charles Darwin Research Station (CDRS), establishment of the Galápagos National Park (PNG), and initiation of the Galápagos International Scientific Project.

In order to access the scientific literature on the Galápagos since 1978, we conducted a computer based search of commercial electronic bibliographies. In Table 1, these data bases are listed at the left. As an example of their coverage, the Aquatic Sciences and Fisheries Abstracts (ASFA) service scans over 5,000 journals around the world.

Nevertheless, it must be recognized that important articles can be missed by computer-based search techniques because of failure on the part of authors to include appropriate "key words," which is how papers are categorized within the computer.

Table 1 gives the number of citations each year for literature on the Galápagos and on El Niño events. The print out of annotated references, numbering about 1,800, has been presented to Msc. Arcos for use by the Technical Committee.

Finally, two recent compendia with valuable information and perspective for the Galápagos marine reserve are listed below:

1. Perry, R. (ed). 1984. Galápagos. Key Environments. UUCN Pergamon Press, New York. 321 pp.
2. Robinson, G. and E.M. del Pino (eds). 1985. El Niño en las Galápagos: El Evento de 1982-1983. Publicacion de la Fundacion Charles Darwin para las Islas Galápagos, Quito, Ecuador. 534 pp.

Figure 1. Plot showing numbers of Scientific References on the Galápagos in the Smithsonian Institute Bibliography, 1800- present.

GALAPAGOS									
	1978	1979	1980	1981	1982	1983	1984	1985	1986
Biosis	43	93	49	45	40	93	50	43	31
Oceanic	20	24	10	18	23	30	23	9	5
Chem. Absts.	7	14	17	14	12	38	8	7	5
NTLS	2	3	6	2	1	0	2	2	2
Georef	23	57	75	54	56	87	38	55	16
ASFA	28	33	41	27	29	40	23	15	4

EL NINO									
	1978	1979	1980	1981	1982	1983	1984	1985	1986
Biosis	3	2	4	0	1	8	15	38	16
Oceanic	6	4	5	3	13	49	41	40	15
Chem. Absts.	1	0	1	0	0	1	1	2	2
NTLS	5	2	1	3	9	12	17	15	9
Georef	1	0	0	1	0	1	10	4	11
ASFA	21	4	11	5	12	65	54	42	15

Table 1. Chart of the numbers of computer-based literature searches requesting information on the Galápagos Islands and on El Niño, 1978 - 1986.

Physical Oceanography of the Galápagos Islands

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Introduction

We cannot talk about the oceanography of the Galápagos Islands without familiarizing ourselves with the oceanography of the Eastern Tropical Pacific. The oceanographic conditions of the Islands are determined principally by the action of the Equatorial Undercurrent, the seasonal fluctuation of the Humboldt Current and the bathymetry.

The equatorial area to the east of the Galápagos represents a transition zone between the tropical and subtropical regimes where the superficial water masses involved are composed of a mixture of different kinds of water originating in the regions before mentioned.

It has to be pointed out that the Galápagos Islands lie in an unusual location: they are situated at a converging point of one of the major current systems of the Eastern Pacific. Although the Islands are located at the equator they can be classified as subtropical islands. (Fig 1)

Figure 1. Map showing the islands that comprise the Galápagos Islands.

The Oceanography of the Equatorial Region

The principal oceanographic and atmospheric characteristics of the Eastern Tropical Pacific are the following:

The Surface Tropical Water (STW) and the Surface Subtropical Water (SSW) are located north and south of the equator, respectively. Below them is located the Subsuperficial Equatorial Water (SSEW) (Figs. 2 and 3).

Figure 2. Map of the distribution of water masses in the Eastern Tropical Ocean.

Figure 3. Map showing the oceanographic and atmospheric characteristics of the Eastern Tropical Pacific Ocean.

The Surface Tropical Water (STW) is characterized by its low salinity due to an excess of precipitation over evaporation. Temperatures higher than 25°C and salinities lower than 34 ppt are present in this water mass and its thickness is restricted to the thickness of the mixed layer (20-50 m). In this area however, the temperature and salinity undergo seasonal changes. During the months from December to April salinity is higher due principally to the major transfer of heat toward the ocean and high evaporation. During the months between May and October a decreased solar radiation causes a decrease of the temperature.

The Surface Subtropical Water occurs in regions where evaporation exceeds precipitation. It is characterized by high salinity and a fluctuation of the temperature around 28°C. Its northern limit runs along the equator and it is separated from the South American continent by the Peruvian Coastal Water that is a result of a horizontal mixture between the Surface Subtropical Water and upwelled water of low temperature and low salinity.

The SSEW also occurs in this region; it has very distinct characteristics of temperatures between 13 and 15°C and salinities between 34.9 and 35.1 ppt. The accumulation of this water mass in the Eastern Pacific is a result of transport toward the east of the Equatorial Undercurrent better

known as the Cromwell current. In general this mass is thought to be a mixture of the Surface Subtropical Water and the Antarctic Intermediate Water.

The boundary between the tropical regime of warm water with low salinity from the Panama Bay and the cold, very salty subtropical water of the Humboldt Current is called the Equatorial Front. This Front extends from the Ecuadorian coast near the Gulf of Guayaquil through the northern part of the Galápagos Islands (0-3°N) and produces strong gradients in salinity and temperature between 1°S (26C - 33 ppt.) and 2°S (19C - 35 ppt.).

Figures 4 and 5 show a section of hydrographic data taken along 92° W by the BAE ORION during the October 1984 cruise. We can see the presence of Surface Tropical Waters north of 0° with temperatures higher than 25°C and salinities of 34.2 ppt. and Surface Subtropical Waters south of 2° 30" S. Upwelling waters are located around 2° S as well as a strong thermohaline gradient corresponding to the presence of the Equatorial Front. We also can see the nucleus of the Equatorial Undercurrent characterized by the Subsuperficial Equatorial water between 100 and 200 m depth.

FIGURA N°4

FIGURA N°5

Figures 4 and 5. Vertical temperature and salinity sections taken along 92°W on the BAE ORION, October 12 - 24, 1984.

Current Systems and Upwelling

The Equatorial Undercurrent and the Humboldt Current are principally responsible for the dynamics of the waters in the equatorial region of the Galápagos Archipelago. The Equatorial Undercurrent is restricted to an area between the 2°N and 2°S and its mean thickness is approximately 200m. The nucleus is generally found at a depth of 100 m with diminishing depth towards the east. Its maximum speed occurs between 50-150 m depth as it approaches the Islands of Fernandina and Isabela its velocity decreases and the flux goes towards the surface causing upwelling of cold and nutrient rich waters, resulting in high productivity in this area during most of the year. East of the Islands the Undercurrent is very weak.

During the cold season the speed of this current decreases before it crosses 96° W; part flows to the northern part of the Galápagos and a small weak branch flows to the south. (Knauss, 1966).

According to hydrological observations and analysis carried out in the archipelago (Houvenaghel 1973, 1974, 1978) the decay of the Equatorial Undercurrent in the vicinity of the Galápagos and its deviation, induced by the bathymetry, appears to be the most important feature of the oceanography of the Islands. The resulting upwelling is due to the action of superficial currents.

A cold water patch is always located west of the Isabela Island, even during the warm season, expanding its area and lowering its temperature especially south and east of the land region during the cold season (Fig. 6).

FIGURA N° 6

Figure 6. Bathymetric charts showing the currents and upwelling areas around the Galápagos Islands.

Temperature and Salinity

Subsurface temperatures in the equatorial region around the Galápagos Islands display variability in space and in time. The west and southwest region of the archipelago have colder temperatures than those for the north and northeast.

Surface Tropical Waters, covering most part of the archipelago during warm season, disappear from this region at the end of April. It is replaced by flow of cold salty water from the Humboldt Current. The maximum extension of water with salinities higher than 35 ppt. occurs at the surface during May-June. However, the 34 ppt. isohaline appears first in the north and east region of the archipelago reaching 1°N in September. (Fig. No. 4).

Conclusions and Recommendations

The circulation in the Eastern Tropical Pacific is important not only because it determines the climate of the archipelago but also because it provides the principal way for transporting organisms. This can in one way or another influence the ecosystems of the Islands.

We have a fairly extensive knowledge of the large scale oceanographic conditions of the equatorial region of the Eastern Pacific, but poor understanding of the inner waters of the Galápagos Islands, the dynamics of currents on the Galápagos platform.

This research must be increased not only because of its importance regarding the marine ecosystem but also because it is a very useful tool for the regional planning in the Islands.

It is necessary to continue with interdisciplinary agreements among interested entities such as the Charles Darwin Research Station, the National Fisheries Institute (INP), the Center for the Remote Sensing of Natural Resources (CLIRSEN), and the Oceanographic Institute of the Navy (INOCAR), for the monitoring and reciprocal exchange of data, research and, especially, ideas for conducting specific interdisciplinary projects.

Physical Oceanography and Meteorologic Features of the Galápagos Islands

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As a part of the oceanographic studies in the equatorial Pacific Ocean, the Oceanographic Institute of the Navy (INOCAR) maintains a constant program to monitor meteorological parameters in the Galápagos Islands, specifically at the San Cristobal station. Furthermore, a program of "opportunity ships" using the M/N BUCANERO provides sea surface temperature observations around the Islands during touring cruises every 21 days.

Data obtained in this way have correlated well with other studies and are useful for documenting the changes that have occurred in the Islands and the consequences to the biota due to extreme seasonal variation.

Meteorological Records and Variability

There exists in San Cristobal a meteorological station that has records of precipitation and air temperature since 1951, of atmospheric pressure since 1969, and of sea surface temperature and salinity since 1974.

Figures 1 and 2 indicate the highest values of precipitation obtained in 1953, 1957, 1975, and 1982-83. The greatest positive anomalies of air temperature were obtained in 1951, 1953, 1957, 1965, 1972, 1976 and 1982-83, of surface salinity in 1976 and 1982-83. The greatest negative anomalies of atmospheric pressure occurred in 1966, 1972, 1976, and 1982-83, of surface salinity in 1976 and 1982-83. All these deviations coincide with warming events and, in several cases, with El Niño events (1953, 1957, 1969, 1972, 1976, 1982-83).

Oceanographic Information Obtained by M/N BUCANERO

The M/N BUCANERO began to take sea surface temperature data in 1983. Every 21 days the vessel makes a trip toward the Galápagos Islands from Guayaquil and observations of sea surface temperatures are made where the ship anchors. These sites are sufficiently far offshore so that the observed temperatures are not modified by the presence of land.

Our analysis describes sea temperature variability and the movement of water masses through the Islands, without including the cause of these changes. Generally, seasonal variation in the sea temperature is described and brief comments are made about the 1982-83 El Niño Event. Graphs are presented to show the typical as well as extreme temperatures.

ESTACION SAN CRISTOBAL
ACUMULADOS DE PRECIPITACION

ESTACION SAN CRISTOBAL
ANOMALIAS DE TEMPERATURA DEL AIRE

ESTACION SAN CRISTOBAL
ANOMALIAS DE SALINIDAD

Figure 1. Time series plots showing monthly precipitation, air temperature anomalies, and salinity anomalies recorded at San Cristobal Meteorological Station, 1948 to 1987.

Figure 2. Time series plots showing monthly sea temperature anomalies and atmospheric pressure anomalies recorded at San Cristobal Meteorological Station, 1948 to 1987.

In 1983, between January and May, temperatures varied from 30°C to 27°C; from July to December from 22°C to 24°C. This range is normal. We also observed an upwelling to the west of Isabela Island with a temperature of 19°C. (Figs. 3 and 4).

In 1984 we observed normal warming in this region from January to March with a range of temperatures between 26°C and 23°C; in April an upwelling of 19°C appeared. From May to December, the retreat of warm waters started and the Humboldt's flow became stronger so cold waters arrived at the Archipelago reaching temperatures between 21°C and 19°C. The upwelling had temperatures around 17°C. (Figs. 5 and 6).

FIGURA Nº 3 November 18 - 23, 1983

FIGURA Nº 4 April 23 - 27, 1983

FIGURA Nº 5 April 13 - 21, 1984

FIGURA Nº 6 August 17 - 25, 1984

Figures 3 - 6. Water temperatures in the area of the Galapagos Islands, taken aboard MN Bucanero.

The year 1985 was characterized as a cold one. This is reflected in the sea surface temperatures which in January ranged between 20°C to 23°C in the upwelling areas down to 18°C. In March and April a maximum temperature of 26°C was observed. From June to October temperatures fell from 21 to 19°C, with the upwelling water at 17°C (Figs. 7 and 8).

In 1986 we observed the normal pattern of temperature from January to April, between 23 and 27°C. From April to August the temperature remained between 20°C and 24°C. In November they rose to 25°C (Figs. 9 and 10).

FIGURA N° 7 January 14 - 25, 1985

FIGURA N° 8 April 9 - 18, 1985

FIGURA N° 9 April 1 - 10, 1986

FIGURA N° 10 Jan. 28 - February 5, 1986

Figures 7 - 10. Water temperatures in the area of the Galápagos Islands taken aboard M/N Bucanero.

Conclusion and Recommendation

As we have observed, the change that takes place in air temperatures in the Galápagos Islands is similar to that of sea temperature. The marine biota experiences very high changes of temperature which can produce a tremendous impact.

Collection of information and on site sampling are effective ways to obtain oceanographic information when accompanied with quick transport, from the sampling points to the receptor center. It is necessary to combine this work with sampling using remote sensors such as satellites, that give synoptic information over a large area. The data obtained on site has to be of sufficient quality as to be useful in calibrating satellite data.

The program of opportunity ships provides us with a source of effective and extremely cheap information and must be maintained.

Once the data has been obtained by satellite and gathered in the reception centers, it should be available from institutes like NOAA and the IGOOS and to national institutes that require data for technical reports or for scientific and practical uses.

I want to emphasize that the help which INOCAR needs from institutions involved in oceanographic studies lies in the area of technical advisors, equipment and training to improve investigations that already have been started or to begin new projects.

Discussion

- Are records available for water temperature that enters the ship's engine rooms by the pumps for the cooling systems? This information should be available in monitoring the equatorial sea oceanographic conditions.
- The upwelling of Equatorial Undercurrent west of Isabela Island not only varies with the season, its variation in intensity is influenced by special events such as anomalies like El Niño decay of the southeast trade winds and strengthening of the South Equatorial Current.
- Sea surface temperature observations obtained by the opportunity ships program should be taken far enough offshore to facilitate coordination with satellite imagery for which surface truth is needed.
- An Atlas of sea surface isotherms climatology around the Galápagos should be prepared using the data obtained.

Variability of Oceanic Conditions of the Western Galápagos Islands

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Physical Oceanography studies by the Oceanographic Institute of the Navy (INOCAR) are conducted to collect information on the dynamics of water masses and other regional phenomena.

Investigators depend heavily on information collected during ocean cruises. INOCAR started a series of systematic oceanographic cruises in 1971. The range of these early cruises was extended to encompass the Galápagos Islands in 1978. Periodic cruises collect information along meridian 92°W from 1°N to 4°S including the Bolivar Channel located between the islands of Fernandina and Isabela.

Temperature and salinity data obtained during these cruises will be discussed. Analysis of these data provides insight into the seasonal variability of oceanic conditions. Two distinct seasons occur within the islands: the first occurs between May and November and is distinguished by strong trade winds which fall off during the second season -- December through April. During this second season, variations in water masses result in warmer water temperatures.

Figures 1 and 2 present data from September 1985 when surface temperatures were less than 21°C. The presence of warm water was observed North of the equator corresponding with a tropical equatorial water mass with high temperature and low salinity. The 15°C isotherm was found in depths ranging from 50 to 70 m, typical of this season. Low water temperatures, with a nucleus of high salinity (35.2 to 35.4 ppt, characteristic of this area), and waters less than 21°C were also encountered on the west side of Isabela and are related to the subsurface equatorial current.

During this season, cold and salty waters rich in nutrients, the surface expression of upwelling, were present off the west side of Isabela. Information on this upwelling is presented in Figures 3 and 4. At the same time, warm waters with lower salinity were observed east of Isabela. This is clearly evident in Figure 5 which corresponds to observations made during the month of October 1984, but it is the previous year that we wish to analyze since seasonal conditions were more typical in that year. Figures 5 and 6 show a strong temperature and salinity gradient to the north between 1°S and 1°N. This strong gradient indicates the presence of the Equatorial Front which had started to descend. During this season, this front normally occurs north of the Galápagos Islands. Upwelling of cold salty waters was also observed between 3°S and 1°S. The strong thermocline observed in Figure 5 between 15°C and 13°C is associated with subsurface equatorial currents and attributed to strong vertical mixing that

Figure 5 - 6. Vertical temperature and salinity sections taken along 92°W from 1°N to 4°S, October 12 - 24, 1984.

Figure 7 - 8. Vertical temperature and salinity sections taken along 92°W from 1°N to 4°S, February 3 - 14, 1986.

develops in the nucleus of the equatorial countercurrent, confined to depths of 50 to 150 m. The thermocline is stronger during this season as winds are stronger and more consistent.

Typical oceanographic conditions encountered during a cruise in February 1986 are depicted in Figures 7 and 8. Surface temperatures varied between 24 and 26°C. A slight upwelling of cold water with salinities of 35 ppt was observed around 1°S. Evidence of this upwelling is presented in Figures 9 and 10. The existence of cooler water west of Isabela and warmer waters to the east of the island was observed. Also, the horizontal distribution of salinity reveals upwelling of water with salinity of 35 ppt to the west with lesser salinities to the east.

Figures 9 - 10. Contours of sea surface temperature and salinity in the waters surrounding the Galápagos Islands, February 3 - 14, 1986.

The figures demonstrate that upwellings of cold salty waters rich in nutrients are always present west of Isabela Island and increase in intensity when the equatorial subcurrent and trade winds become stronger. Based on this evidence, we can say that seasonal variability of oceanographic conditions in the area are influenced by the position of the equatorial front which contains the zone of interaction between differing masses of water. When the front is located between 0 and 3°N, during the season of strong trade winds, cold waters with relatively high salinities flow through the islands. During the remainder of the year, the equatorial front shifts south replacing the cold waters corresponding to superficial tropical waters.

Figures 11 - 12. Vertical temperature sections taken along 92°W, December 9 - 20, 1986 and February 7 - 24, 1987.

We also know that oceanographic conditions on the section of the meridian 92°W vary from normal to totally anomalous. In Figure 11, which shows the oceanographic conditions of December 1986, we observe a slight presence of the equatorial front located between 1°S and 1°N and characterized by a strong temperature gradient; around 2°S a slight superficial upwelling is encountered. The 15°C isotherm is located between 50 and 150 m of depth. Within the territorial waters of Ecuador, it is evident that the depth of this isotherm began to increase in December. Two months later, in February 1987 (Figure 12), the 15°C isotherm had descended below 150 m indicating a totally anomalous situation which is manifested on the surface by temperatures as high as 28°C. There is no indication of the presence of upwelling or a thermal front but there are good indications of stratification of water masses.

We can summarize by saying that seasonal differences in oceanographic conditions within the zone exist and are indicated by anomalous conditions as identified previously.

Finally, I believe that systematic monitoring of oceanographic data around the Galápagos Islands must be increased if we are to increase our understanding of the dynamics of water masses entering the zone.

Origin and Geological Setting of the Galápagos Islands

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Introduction

The Galápagos Islands (16 large and small islands and some rocks emerging above the sea) are situated approximately 600 miles west of South America and about the same distance east of the Eastern Pacific Rise. The islands are volcanic, having originated during the Plio-Quaternary era. The islands constitute a complex system in the Eastern Equatorial Pacific. Their recent origin has been observed by different investigators since Darwin's time, using lava-dating techniques to determine their age. A more complete geologic interpretation of the islands came later when scientists from all over the world tried to explain the origin of the select flora and fauna which is intimately related to the origin of the Islands.

Surrounding the Galápagos Islands, there are some important morphological characteristics which are linked to the development of their tectonic origin. The most important are the Carnegie and Cocos submarine ridges formed by a hot spot actually under Isabela or Fernandina Island (Holden and Rietz, 1972; Morgan, 1973; Hey, 1977; Lonsdale and Klitgord, 1978) (Figure 1).

Figure 1. Map showing the location of the Galápagos Islands in the Eastern Equatorial Pacific and the principal geological characteristics that surround the islands.

North of the islands is the Cocos-Nazca spreading center, where new oceanic crust is generated. This spreading center is offset by several transformation faults through which it is displaced North and South (Figure 1). The southernmost point of the axis of the spreading center is located 150 km north of Darwin Island. The westernmost part of the spreading center meets the Eastern Pacific Rise in a triple junction.

Origin

To understand the evolutionary trend of the Galápagos Islands it is necessary to review the tectonic evolution of their settled area. After the proposition of the plate tectonics theory around the 1960's, big projects were designed to test and develop probable reasons for the evolution of specific areas. The Cocos-Nazca axis was the target of many investigations during the 1960's and 70's. Results of these studies were the theories of Van Andel and others (1971); many investigators tried to reconstruct the evolution of the area.

After the discovery of an anomalous heat flow in the area (Sclater and Klitgord, 1973; Williams et. al., 1974) a large project was created to study this phenomenon. A large amount of magnetic and bathymetric information was collected and made available. Results of these studies include the proposed hypotheses of Hey (1977), and Lonsdale and Klitgord (1978) which are currently the most widely accepted. The Cocos and Carnegie Ridges, along with the rough-smooth boundary depicted in figure 2, comprise the major components of these hypotheses.

According to this view, the Cocos and Carnegie Ridges were created by the same hot spot that now forms the Galápagos Islands. The trend followed by their formation is the direction of movement of the plates to where they actually stand. The Carnegie Ridge indicates movement eastward of the Nazca Plate, and the Cocos Ridge indicates movement of the Cocos Plate.

Isochrones were obtained from the correlation of magnetic lines, and are shown in figure 2. These isochrones are parallel to the Cocos-Nazca axis inside the rough-smooth boundary, except on the Southeastern side, below the Carnegie ridge, where they trend 065° paralleling the Grijalva Scarp (Fig. 2). The southeastern isochrones have been interpreted as the direction of the formation of oceanic crust through the original Cocos-Nazca spreading center.

The asymmetric-accretionary model of Hey (1977) suggests that the rupture of the Farallon plate commenced about 26 to 25 million years ago (MYA), through a large fracture zone in the East Pacific Rise. A group of stresses created along the northern section of the East Pacific Rise to the North American continent is believed to be responsible for this tectonic event. It also coincides with the high volcanic activity in Mexico, Central America, and South America found at that time (Dott, 1969). The new axis created new oceanic crust for the Cocos and Nazca Plates.

Figure 2. Important magnetic and morphological features in the spreading center of the asymmetric accretionary model of Hey. (Hey, 1977)

Later tectonic reorganization of the area at about 23 MYA resulted in the East-West trend of the axis. The Galápagos hot spot is an important component in the development of the axis. It has been placed back in time at about 25 MYA by Hey (1977), who suggested that it tends to force the relocation of the spreading rift. The Carnegie and Cocos Ridges were formed about 23-20 MYA by this hot spot as the source of magma was under the Nazca Cocos plates.

The last major tectonic reorganization occurred from 10 to 5 MYA. It corresponds to the western migration of the Eastern Pacific Rise. From 6 MYA to the present, the Galápagos hot spot has been under the Nazca plate forming the Carnegie and Cocos ridges and the Galápagos submarine platform where the Galápagos Islands are situated.

Geological Setting

The Galápagos Islands are situated on the western part of the Galápagos submarine platform which has a maximum depth of 1300 meters. This platform is connected with the Carnegie Ridge to the east and is abruptly cut to the west where depths of 3000 meters are found a few miles from its edge. The volcanoes follow an E-W and NW-SE alignment through the Islands. These Plio-Quaternary Islands can be divided into five units according to their composition of lava, alignment of volcanoes, age, and morphology.

The alignment of volcanoes is presented in Figure 3; also, uplifted marine volcanic terrain is shown on the southeastern side, by the dotted line. This uplifted block constitutes the first unit of the Islands. Espanola, Santa Fe, Baltra and Seymour Islands and a small part of the Santa Cruz Island are composed of this uplifted volcanic terrain, and are defined by a fault belt to the northwest. The general composition of these islands is olivine-alkaline basalts; marine carbonates appear in some places stratified with lava (e.g. Pta. Suarez). Some pillow lavas occur on Baltra Island along with massive basalts which are older than 1.47 MY. The oldest material has been found on Santa Fe Island.

The central-southern group of Santa Maria, San Cristobal and the main part of Santa Cruz Islands are eroded tops of volcanoes that appear on both sides of the uplifted blocks of volcanic terrain. The Santa Maria and especially the eastern portion of San Cristobal have smaller and younger craters. The composition of lavas are olivine-alkaline basalts; palagonitic tuffs are found frequently. The youngest lava in Santa Maria is older than 0.7 MY and lava from Santa Cruz is younger than 0.7 MY.

The large island of San Salvador and the smaller islands Pinzon and Rabida in the central part of the Archipelago are comprised of volcanic rocks with a high variation in composition. San Salvador is a complex island formed by an important volcano in the northeast and a large number of smaller cones in the east and south. Some volcanic explosions have occurred during the last 300 years. The oldest lava is composed of olivine basalts and picrites and iron enriched tholeiitic basalts. The youngest flows are olivine-alkaline basalts. Pinzon and Rabida Islands are the remains of volcanoes varying in composition from olivine-porphyrritic basalts, tholeiitic ferrobasalts and icelandites to siliceous trachytes. The volcanic activity has been periodic in these islands from the early Pleistocene to modern times.

North of San Salvador, there are three small islands: Marchena, Genovesa, and Pinta. They represent eroded tops of large volcanoes. These volcanoes rise from the ocean on the northeastern edge of the Galápagos platform. The younger islands are situated to the east of the main alignment to the northwest (Figure 3), which continues farther to the northwest toward the small Wolf and Darwin Islands outside of the platform. There are two submerged volcanoes southeast of Wolf Island. Genovesa Island developed two calderas on its top, which do not emerge above sea level. Marchena is formed by the remains of a volcano, and lava flows have covered the original top of the caldera. Sporadic fumarole activity is still observed. Pinta

[illegible]

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The last division of islands are the largest, Isabela and Fernandina, situated to the west. Some volcanoes on these islands are active and are composed of olivine-poor tholeiitic basalts. Isabela appears as two islands recently joined. The southern part consists of two volcanoes, Sierra Negra and Cerro Azul, aligned NE-SW, whereas the northern mountain chain including the Alcedo, Darwin, and Wolf volcanoes run SE-NW. A sixth volcano, Ecuador, has been eroded, faulted and submerged at the Northern edge of the Island. The Sierra Negra is the biggest and probably the oldest volcano. It has erupted at least four times in this century and has the most active fumaroles. Cerro Azul, one of the youngest volcanoes has erupted at least five times since 1943. The Alcedo is the smallest and least active volcano. Darwin has a symmetric form and does not show evidence of historic eruptions. Wolf is the highest and most active volcano on Isabela Island; it has erupted at least eight times during the last one hundred years. Wolf volcano is connected to the Ecuador volcano by a series of cones through fractures. Fernandina and the Wolf are very similar in configuration. The last major eruption of Fernandina was in 1968, when its caldera collapsed 300 meters. This is the most active of the Archipelago.

Discussion and Conclusions

Geologic studies in the Galápagos have been oriented mainly toward establishing the relationship between the origin and characteristics of the Islands and the living organisms inhabiting them. Following the discovery of the unique fauna and flora on the islands, scientists studied the possible ways animals migrated to the islands. New concepts about migration evolved after the tectonic history of the Islands revealed that no bridges to the continent had ever existed. Geology has definitely helped to increase our understanding of how and when life began in the Archipelago. It continues to contribute to increasing knowledge of evolutionary patterns in the Archipelago.

Despite the fact that the relationship of benthic organisms with the characteristics of the ocean floor around the Galápagos has increased, knowledge of this topic is poor in comparison with studies of the terrestrial environment. A better knowledge of the Galápagos submarine platform would add information. The bathymetric charts available from the area were obtained from the data collected by the U.S. Naval Office during the 40's and from ships passing through the Islands. It is important, to complete this information to understand the diversity of habitats of marine organisms, mainly benthic, around the Galápagos. This, along with the preparation of navigation charts, is precisely the aim of the Oceanographic Institute of the Ecuadorian Navy (INOCAR). The Institute has a cartographic plan dedicated to improving navigation in the Archipelago (Figure 4). While doing this important job, bottom samples will be taken to study the textural and lithological configuration of the ocean floor. This information will contribute to studies of the marine environment in the area and, ultimately, to better preserving it.

Figure 4. Cartographic Plan of the Insular Region of the Oceanographic Institute of the Ecuadorian Navy (INOCAR). Numbers inside frame identify each chart.

The origin and geology of the islands can be determined by geologic studies of individual islands and information such as bathymetry and lithology of the marine area around the Galápagos Islands. It will significantly improve our understanding of the ways that we can preserve one of the marvels of this world, the biota of the Galápagos Islands.

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Sedimentology

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A marine plan must consider the three factors that shape the marine environment: biology, oceanography, and geology. These three areas are intimately linked and knowledge of each acting alone and in concert are needed to plan and to predict the outcome of any policy. Most emphasis has been placed on the biologic and oceanographic spheres of study, with geology the forgotten member of this important triad. "Remarkably little marine geology has been done in the Galápagos" (Tom Smitkin, Personal Communication).

Previous geological work has focused primarily on terrestrial geology including volcanology, petrology, and some paleontology. Absent is research on coastal processes, shelf geology, and sedimentology that is vital to our understanding of biological distribution, geologic hazards, and coastal planning.

Current sedimentologic research in the Galápagos is focused on an uplifted carbonate and basalt shallow-water shelf at Urvina Bay, Isabela. At Urvina Bay, researchers from the University of California, Santa Cruz, (Colgan and Malamquist), the University of Hawaii (Smalley) and others are examining topics in sedimentology, coral reef development, paleontology, carbonate diageneses, and coastal processes. Urvina Bay offers an unparalleled opportunity to examine marine geological processes, and should yield important information concerning sediment formation and distribution as well as sedimentary history (eg., the transition from clastic to carbonate environments). More esoteric research concerns paleontological studies in taxonomy and experimental paleoecology. Studies of coastal processes and beach development are not a major thrust of the current efforts at Urvina Bay. But given that beaches and mangroves appeared here a short 33 years ago, studies concerning their formation could be conducted and combined with studies of the paleobeaches and mangroves (stranded as much as a kilometer from the sea) could increase understandings of Galápagos shoreline processes.

The work at Urvina Bay notwithstanding, Galápagos marine sedimentologic research is all but absent from the literature. Given this lack of knowledge, I would like to discuss areas of possible research. I have divided possible Galápagos marine geological research into near-shore and shelfal studies.

Near-shore studies include coastal areas that are most affected by human activities and in turn present a potential hazard to human endeavors. The most vulnerable coastal geological resource is the beach environment. With the current ban on removing beach sand and increased

population growth, there will continue to be a demand for sand construction. Presently, mainland sources fulfill the Islander's needs. However, in the foreseeable future building demands may call for a cheaper internal source of carbonate and volcano-clastic sands. In the Galápagos, there are two marine sources for sand: beaches and shallow near-shore shelf deposits. The prohibition of beach sand exploitation means that near-shore sources may be the next best source of sands. Because of possible harmful effects of submarine excavation, it should be strongly discouraged until research is conducted and management plans are made.

The building of ports and anchoring sites could change current patterns, thus altering sediment distribution patterns. Such activities could result in the shallowing of bays and harbors from the deposition of sediment and the erosion of coastal deposits. Of these two results, the erosion of coastal deposits is most serious. Unlike continental coasts, terrestrial sediment input on the Galápagos coast is low; much of the coastal material consists of locally reworked deposits. Without a large external sediment source to recharge these deposits, they are extremely vulnerable.

A potential hazard to the marine environment is increased sedimentation from agricultural practices and sand mining. Increased sedimentation is detrimental to marine life causing death and loss of habitat. Presently this is not troublesome, but with the increase in human populations and a concomitant increase in construction and agriculture this may not always be the case.

Another potential geological hazard to the Galápagos is oil drilling off the continental coast of Ecuador. Oil drilling itself presents no detrimental effects to the Galápagos, but the specter of a blow-out does. A blow-out that lasts days and with thousands of barrels of crude oil released could reach the Galápagos. For this reason, we urge that all drilling be performed with the most advanced anti-blowout devices.

Surrounding the island is a one-hundred fathom volcanic shelf that rises from the deep sea. The distribution, texture, composition, and thickness of the shelf sediments, as well as the sources and processes that form and shape them are unknown. In benthic biological communities, sediment texture and distribution control animal distribution. Understanding of sedimentary patterns on the shelf yields valuable information about faunal distribution. A first step in advancing our knowledge is the development of surface sediment distribution maps by systematically sampling and analyzing shelf sediments.

Furthermore, the sediment column on the shelf and in the adjacent basins contain information about the history and development of the Galápagos. Cores and seismic sampling could help to better understand shelf development, paleontology and paleo-oceanography of the Galápagos.

Shipboard research can enhance our knowledge of marine geology in the Galápagos. This research should integrate geophysical methods with coring and surface sediment sampling. Two important geophysical tools are side-scan sonar and sub-bottom seismic profiler. Sedimentary processes can be inferred from side-scan sonar that can image the sea floor bottom for sediment surface texture and bed forms. Seismic profiling determines depth of sediment thickness and

subsurface features.

This geophysical data, to be reliable, needs to be tested by taking tangible bottom samples with cores and dredges. Age determination from cores is required to determine sediment accumulation rates. Ages along with facies analyses could help to piece together the geological history of the Galápagos.

Marine geological research is often an expensive undertaking because of ship costs and equipment. A possible source to do some of this work is the United States Geological Survey (U.S.G.S.). The Pacific Marine Branch has a long and successful history of working with Pacific Nations. A cooperative project with U.S.G.S. would be beneficial to all involved.

Beaches

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Although beaches make up only a small portion of Galápagos coastline, they are disproportionately valuable for a) turtle meeting sites and pinniped haul-out areas; and b) resident and tourist recreation sites. In the recent past, beaches were quarried for construction aggregate, resulting in beach attenuation; this practice has evidently been discontinued. It would be presumptuous to imply that beaches within the Galápagos are not important for additional unknown reasons. The special value of beaches makes it imperative that they are addressed in a Marine Resources management plan.

The history of beach management failures around the world underlines our poor understanding of these dynamic coastal sedimentary environments. Early stages of potential management problems may be evident at Puerto Villamil (Isabela), a Galápagos urban area sited on a barrier beach. North American efforts for stabilizing barriers appears to have been incorporated into a policy in beach management in the form of sea wall and dune construction. Ultimately this approach will fail because of the inherent mobility of beach deposits.

It is generally true that beaches of the islands are not large; they occur commonly as small pocket deposits along the cliffed shore. Luxuriant deposits occur at a few sites such as Tortuga Bay on Santa Cruz, Gardner Bay on Espanola, and at Puerto Villamil where a sizable barrier beach occurs complete with lagoons. As is so commonly the case in the Galápagos, the study of beaches also offers potentially rich and stimulating scholarly rewards. For example, in this active tectonic area, uplifted beach deposits can be visited at Urvina Bay, on Isabela, almost 1 km inland from the present shoreline. At Tortuga Bay, the beach material appears to consist of reworked fossil material, Pleistocene eolian carbonate sands, now reworked into the traditional beach landform after a fascinating and complex history (Colgan, personal communication). An additional interest of a few beaches is the lagoonal environment created behind them. This lagoonal environment typically becomes hypersaline in the arid coastal setting and can support the food chain that ultimately attracts Flamingos at Puerto Cormorante on Floreana and at the Pozzo's of Puerto Villamil on Isabella.

Compared with the cataclysmic processes typical of the Galápagos, the threat of global sea level rise, which causes concern for many parts of the world, seems almost a trifling matter. Nevertheless, landward retreat of the shoreline, particularly on the barrier beach of Puerto Villamil, could be a costly local problem. In the vicinity of this urban area a system of bench-marks should be established and the rate of shoreline transgression measured over a scale of tens of years.

The best national beach policy for the Galápagos is to let nature take its way, rather than to finance beach nourishment programs or structural approaches to "stabilization". Funds should be used to move threatened dwellings or other coastal projects. This approach not only corresponds with current wisdom, but is consistent with a tourism policy that recognizes the natural systems "bent" of the Galápagos tourist.

Studies of beaches on the Galápagos might profit from the approach of "sources, pathways, sinks" in which the sources of carbonate material pose a particularly interesting question. The rate of production of carbonate materials at this tropical site seems only partially explained by the mortality of corals incurred by quasi-periodic El Niño events. The striking paucity of carbonate sand would appear to represent yet another Galápagos conundrum.

**Remote Sensing of Primary Productivity:
Recommendations for Future Remote Sensing Research
in the Galápagos Island Marine Reserve**

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Remote sensing techniques, using both airborne and orbiting devices, film cameras and passive and active scanners, have been shown capable of estimating sea surface temperature (SST), phytoplankton pigment concentration (a function of ocean color), surface wind vectors, sea level, suspended sediment concentrations, bathymetry, and bottom type. The degree of accuracy in each of these applications is dependent upon environmental conditions (e.g. cloud cover and water quality) and, in all cases, coincident field measurements and remote sensing are required. The results are synoptic views of the area of interest. In this sense, remote sensing is more cost-effective than field measurements alone and in most cases yields spatial information that would be impossible to obtain with even the most ambitious of field operations. Yet, on an absolute scale, remote sensing studies may require substantial financial resources. The analysis of scanner data requires a certain level of computer equipment and expertise. It is therefore necessary to clearly identify and rank the types of information that are important and that may be addressed through remote sensing.

An additional consideration is the anticipated continuity of the remote sensing data source. The SEASAT satellite, for example, housed instruments capable of measuring sea surface wind vectors and sea level, but the satellite is no longer in operation and a replacement is not anticipated until the early to mid 1990's. On the other hand, the NOAA series satellites, which are capable of measuring SST to within 0.5°C, are important for weather prediction and, therefore, the U.S. is committed to maintaining and replacing these satellites for the foreseeable future.

Within the Galápagos Marine Resources Reserve (GMRR), there are two major economic activities -- commercial and artisanal fishing, and tourism. Each of these activities is associated with a unique set of management considerations. From a fisheries viewpoint, information concerning maximum sustainable yield and seasonal and interannual variability are important. Although at present tourism has no measurable affect upon Galápagos pelagic fisheries, it nevertheless does impact upon other components of the Galápagos ecosystem and has the potential to adversely affect artisanal fisheries in the near future. Management efficiency of the resources exploited by these activities would be greatly enhanced with a regular monitoring system. Herein lie several possible applications of remote sensing.

Phytoplankton Pigment Distribution

The commercial fisheries around the Galápagos Islands are driven by wind- and current-induced upwelling. Upwelling areas are characterized by cool sea surface temperatures coupled with high nutrient concentrations, thus higher phytoplankton concentrations and thus greater primary productivity. Feldman (Science, 1984, EOS, 1986; Lecture Notes on Coastal and Estuarine Studies, 1986), using advanced very high resolution radiometer (AVHRR) imagery to map SST within the Galápagos Islands and coastal zone color scanners (CZCS) to map phytoplankton distributions, studied the effects of the 1982-83 El Niño upon Galápagos Island upwelling (Figure 1). In non-El Niño years, phytoplankton rich waters generally occur west of Isabela and Fernandina during the dry season (July-March). During the rainy season (April-June) high phytoplankton concentrations tend to occur to the east of Isabela. During the 1982-83 El Niño the normally predictable wind and current systems changed and the resulting upwelling was altered in ways that at present are only partially understood. One adverse effect of the 1982-83 El Niño was a temporary collapse of the artisanal bacalao fisheries. Through periodic monitoring of SST and phytoplankton distributions within and around the GMRR, more thorough understanding of seasonal and interannual upwelling variability should emerge. Ecuadorian fisheries would benefit from a clearer understanding of how El Niño affects Galápagos upwelling.

(A) 1 February 1983

(B) 28 March 1983

Figure 1. Phytoplankton pigment concentrations derived from Nimbus-7 Coastal Zone Color Scanner imagery. Cross-hatched areas represent concentrations greater than 1.0 mg/m³. Darkly shaded area in (B) represent concentrations between 3.0-10.0 mg/m³. In general, concentrations of less than 0.2 mg/m³ were found throughout the region. (A) represents normal conditions while (B) shows the effect of the 1982-83 El Niño event. (Source: Feldman 1985). "Satellite, Seabirds, and Seals". In *El Niño in the Galápagos Island: The 1982-1983 event*. Gary Robinson and Eugenia M. del Pino, editors. pp. 125-130.

To successfully monitor Galápagos upwelling and to measure and perhaps predict the effects of future El Niño events, monthly or bimonthly SST and ocean color imagery would be required. SST information may be gleaned from NOAA/AVHRR imagery. This imagery is collected daily throughout the Galápagos region and may be used to map SST with 1 km resolution (see attached summary "Satellite Remote Sensing Platform for Marine Research"). In the past, ocean color data was collected with the now defunct CZCS. Presently, there are no proven sources of ocean color imagery capable of mapping phytoplankton pigment distributions. Several new ocean color scanners are under development and are due to become operational by the early 1990's (NASA/OCI and SPOT-4).

In addition to the AVHRR and ocean color imagery, a computer-based data storage and analysis system, together with trained operators would be required. The remote sensing data could be purchased in digital form and analyzed in Ecuador. This is important in order to adequately catalog the data and to conduct seasonal and interannual time series analysis. Such a computer system, "earth view," is presently owned and operated by the Center for the Remote Sensing of Natural Resources of the Military Geographic Institute (CLIRSEN). This, combined with a wealth of remote sensing experience makes CLIRSEN the most obvious candidate for carrying out this task.

Tourism

Tourism traffic within the GMRR, if allowed to increase in volume, may eventually adversely affect the island environment. Given that the unique character of the GMRR is a potentially lucrative tourist attraction for Ecuador, several questions must be addressed:

What are the effects of tourism traffic?

Which areas are affected the most?

What are the limits in traffic volume?

To help answer these questions, Ecuador should institute a vigorous annual or biannual survey of the GMRR. The objectives of such a survey would be to identify and map the various land marine environments and to measure year-to-year tourism-induced changes. The initial survey should be conducted while the GMRR is in relatively pristine condition.

Tourism effects upon the GMRR could be measured through annual (or at least biannual) surveys using 1:24,000 color photography (9 inch format) and complementary ground and ocean bottom surveys. Aerial photography is advised over satellite imagery because Ecuador presently has the technology and expertise to conduct the necessary aerial surveys. Similar surveys are conducted annually in Chesapeake Bay through a submerged aquatic vegetation survey program. The aerial photography could be visually interpreted and field-checked and the results transposed onto 1:24,000 topographic maps. Year-to-year changes could be measured simply by overlaying maps from successive years.

Ideally, the survey information should be digitized and stored in a computer-based geographical

information system. This would permit detailed trend analyses directly related to tourist activities. Once again, the CLIRSEN computer system would be ideal for this task.

Conclusions

Two separate GMRR management problems exist, both of which may be addressed through remote sensing -- monitoring the Galápagos upwelling in relation to phytoplankton distribution and productivity and surveying the GMRR ecosystem in order to monitor the effect of tourism.

The successful completion of these tasks requires the ability to computer process digital ocean color and thermal imagery and to store the results in a computer data base. It is evident that CLIRSEN, by virtue of their remote sensing experience and the newly acquired imagery analysis computer, is well suited to carry out these tasks.

Discussions

The variability in phytoplankton pigment distribution evident in CZCS imagery (Feldman, 1984), both within the GMRR interval waters and through the Galápagos region, emphasizes the need to further define and understand monthly, seasonal, and annual variability in wind and current circulation. Such knowledge is necessary in order to estimate primary productivity, a factor which affects Galápagos industrial and artisanal fisheries. The intimate relationship between circulation dynamics and Galápagos Islands fisheries was clearly illustrated during the 1982-83 El Niño episode. The types and information required are:

1. Sea surface temperature distribution
2. Phytoplankton distribution
3. Current circulation
4. Surface wind velocities,
5. Nutrient distributions

Of these first parameters, the first two may be addressed through remote sensing at sufficient spatial and temporal scales. The remaining three must be acquired through in situ measurements. Sea surface temperature distributions are acquired daily with sensors (AVHRR) aboard the NOAA polar orbiting satellites. Historical phytoplankton pigment distributions may be obtained through computer analysis of CZCS imagery. (Further information concerning ordering these data are contained in the attached report "Satellite Remote Sensing Platforms for Marine Research").

Unfortunate for the analysis and phytoplankton pigment distribution, the CZCS is no longer operational. However, the possibility exists that another orbiting scanner, the Landsat Thematic Mapper (TM), may be an adequate replacement, at least until a second CZCS-like sensor can be put into orbit (presently due in the early 1990's). Further research must be conducted in Ecuador to test the application of TM imagery. Relative to the CZCS system, TM bands are somewhat broader and the radiometric sensitivity less. Yet, the fact that one can see variations in

deepwater ocean color within TM imagery suggests that it may be useful. An effort should be made to attract funding, either domestic or foreign, to compare historical CZCS imagery with TM data, preferably for which there exists surface measurements of chlorophyll A concentration.

A second alternative to CZCS imagery, and possibly a complementary data set to TM imagery, is a presently funded study of sea bird feeding habits using radio tracking. Presumably, sea birds are efficient trackers of secondary consumers, the distribution of which could be closely linked to the distribution of primary producers (phytoplankton).

Finally, a recurring theme in not only the remote sensing discussion but topics concerning ecosystem dynamics and the impact of tourism, is the need for a detailed vegetation survey that could serve as a baseline from which to compare future changes. Such a survey should include both terrestrial and benthic species and should identify and map characteristic species communities. This is a classic problem in remote sensing which may be addressed with historical aerial photographic surveys and historical Landsat imagery, both of which presently exist in CLIRSEN. It is advised that CLIRSEN employ their considerable expertise and resources, along with historical field surveys, possibly conducted by Darwin Station personnel, in conducting such a survey.

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SATELLITE REMOTE SENSING PLATFORMS
FOR MARINE RESEARCH

APRIL, 1987

Remote sensing satellites provide synoptic measurements of sea surface temperature, ocean color, pigment concentrations, sea surface topography, depth, bottom features, and surface wind vectors. Archived data types include SEASAT, NIMBUS, GOES, TIROS, NOAA, LANDSAT, AND SPOT. Data attributes and, therefore, applications are satellite specific. Presently, GOES, NOAA, LANDSAT, AND SPOT satellites are operational.

The distribution of SEASAT, NIMBUS, GOES, TIROS, and NOAA data is managed by the National Climatic Data Center (NCDC) in the United States:

NCDC
Satellite Data Service Division
Room 100
World Weather Building
Washington, D.C. 20233
U.S.A.

Landsat data is distributed privately by Earth Observation Satellite Company (EOSAT):

EOSAT
4300 Forbes Blvd.
Lanham, MD 20706
U.S.A.

SPOT is a French satellite configured similar to Landsat and is distributed outside of the U.S. by SPOT Image Corporation:

SPOT Image, SA
16 bis, Ave.
Edouard - belin
B.P. 4359
31030 Toulouse Cedex
France

Sea Surface Temperature: Nimbus-7 (SMMR), GOES, TIROS, NOAA (AVHRR), LANDSAT-5 (TM Band 6)

Surface resolution:

NIMBUS-7, GOES, TIROS, NOAA: 1 km
LANDSAT-5: 160 m

Ocean Color: Nimbus-7 (CZCS), LANDSAT (MSS AND TM), SPOT

Surface Resolution:

Nimbus-7 (CZCS): 1 km
LANDSAT (MSS): 80 m
LANDSAT (TM): 28 m
SPOT: 20 m multispectral, 10 m panchromatic

Visible Bands:

Nimbus-7 (CZCS): 4, 20 nm band width
LANDSAT (MSS): 2, 100 nm band width
LANDSAT (TM): 3, 50 nm band width
SPOT: 3 multispectral, 100 nm band width
1 panchromatic, 300 nm band width

Pigment Concentration: Nimbus-7 (CZCS)

Sea Surface Topography: SEASAT (altimeter)

Accuracy: 65 cm

Depth and Bottom Features: LANDSAT (MSS and TM), SPOT

Sea Surface Wind Vectors: SEASAT (scatterometer)

Surface Resolution: 50 km

Accuracy:

Velocity: 2 m/sec
Direction: 20°

Future Platforms

As existing satellites reach their designed lifetime and eventually fail, new satellites must be constructed and put into orbit in order to insure continuity in coverage. Weather satellites such as the GOES and NOAA series have proven to be immensely useful in weather prediction and so replacement of these satellites is given a high priority. Because the thermal scanners built into these satellites are also useful in ocean research, mesoscale SST coverage of the world's oceans is not expected to be a problem in the future. All other satellite data having oceanographic applications are somewhat limited in demand, at least for the foreseeable future. Ocean color scanners, for example, require radiometric sensitivities that well exceed any useful application to land studies. Continuity in these data types is expected to be tenuous. This is not to say that the future is completely bleak for satellite oceanography. In the past the U.S. shouldered the responsibility of developing and orbiting new remote sensing platforms and devices. Now, other countries are joining the development process. The French have successfully built and orbited SPOT, a scanner similar to the Landsat MSS but which is able to alter view angle. France is committed to building three follow-up SPOT satellites which are expected to insure continuous operation through the next decade. In addition, SPOT-4 will be equipped with a multispectral scanner configured similar to the now defunct CZCS. Japan has recently put into orbit a multispectral scanner that could prove useful in ocean color and productivity research. In addition, the U.S. has developed several new satellite designs which should become reality by the early 1990's. A list of proposed future oceanographic satellites is presented in Table 1.

Table 1.
Oceanographic Satellites Presently Under Development
Or Planned For Deployment During The Next Decade

<u>Satellite</u>	<u>Country</u>	<u>Launch Date</u>	<u>Application</u>
Landsat-6	U.S.A.	When Needed	Bathymetry Turbidity Bottom Features
SPOT-2,3	France	When Needed	Bathymetry Turbidity Bottom Features
SPOT-4	France	When Needed	Ocean Color Phytoplankton Pigment Concentration Bathymetry Turbidity Bottom Features
OCI	U.S.A.	Mid 1990's	Ocean Color Phytoplankton Pigment Concentration
TOPEX	U.S.A.	1991	Sea Level
NROSS	U.S. Navy	1990	Surface Wind Vectors
GOES	U.S.A. USSR Japan	When Needed	Sea Surface Temperature

Acronyms

AVHRR	Advanced Very High Resolution Radiometer
CZCS	Coastal Zone Color Scanner
GOES	Geostationary Operational Environmental Satellite
LANDSAT	Land Satellite
MSS	Multispectral Scanner
NOAA	National Oceanic and Atmospheric Administration
NROSS	Navy Remote Ocean Sensing System
OCI	Ocean Color Imager
SEASAT	Sea Satellite
SMMR	Scanning Multi-frequency Microwave Radiometer
SPOT	Satellite Pour l'Observation de la Terre
TIROS	Television and Infrared Observation Satellite
TM	Thematic Mapper
TOPEX	Ocean Topography Experiment

The Benthic Marine Algal Flora

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Benthic marine algae are a significant component in the primary productivity of the nearshore coastal areas in the Galápagos Islands. They support many herbivore species, including the marine iguana. Some species (i.e. the encrusting coralline algae) are instrumental as reef builders and important in the carbon budget of coastal areas. Because of their nearshore distribution they are likely to be adversely affected by increased human activity in the Galápagos. Human activities that could have a detrimental effect on the benthic algal flora include increased pollution around urban areas, development of port facilities, landfilling and trampling effects by increased numbers of tourist at visitor sites.

A change in the diversity of algal species or a shift in species abundances and distributions associated with such activities could result in a loss of species diversity throughout the entire food web. It is for this reason that marine benthic algae should be strongly considered in the Management Plan for the Galápagos Marine Resources Reserve.

Previous research on marine macroalgae in the Galápagos is presented in the following chronology: information prior to 1964 comes from a presentation given by Dr. Paul Silva (U.C. Berkeley) at the Galápagos International Scientific Project, 1964.

- 1835: The first alga collected and identified from the Galápagos Islands was an encrusting coralline alga dredged from a depth of 12 fathoms by the "Beagle" in 1835 and identified by W.H. Henry (1847). It is significant that the first alga collected was an encrusting coralline as the encrusting corallines appear to be the major primary producers over the entire Galápagos Islands in rocky habitats at all depths.
- 1872-1888: U.S. Vessels "Hassler" and "Albatross" collected algae but specimens were not identified until 1945 when they were included in W.R. Taylor's monograph on algae of the Galápagos.

- 1898-1899: The Hopkins-Stanford expedition visited the Islands and collected 30 species of algae.
- 1924: The "Saint-George" visited the Galápagos. Cyril Crossland who was interested in corals, collected many species of coralline red algae.
- 1932: The Templeton-Crocker Expedition of the California Academy of Sciences on the yacht, "Zaca" made significant collections of algae that were identified by Setchell and Gardner.
- 1934: The Allan Hancock Expedition on the yacht "Velero III" with the assistance of William Randolph Taylor made the first major attempt to characterize the algal flora of the Galápagos Islands, resulting in a monograph on that subject.
- 1962-1964: E. Yale Dawson visited the Galápagos and added to the taxonomic knowledge of the algal flora.
- 1964: Paul Silva collected algae and added to the taxonomic knowledge of the algal flora of the Galápagos Islands.
- 1965-1980: Santelices (Chile) and Abbot (U.S.A.) included the Galápagos flora in a biogeography of Eastern Pacific algae.
- Dr. Gerald Wellington described distributions of intertidal and subtidal benthic organisms, including algae, on many of the southern and central islands that make up the Galápagos Archipelago.
- James Norris and Mark Littler working with the Smithsonian Institute developed two permanent photographic transects including the high intertidal down to 30 m. depth in the subtidal area. These were set up at Punta Espinosa, Floreana, which represent the southern Galápagos environment, and the north, location unknown in an area of generally warm water with little upwelling.
- Other researchers working on the feeding habits of iguanas, Sally Lightfoot crabs, and other herbivores have summarized possible algal food sources in their publications.

1985-1986:

Dr. Matilde Velasco started an inventory of Galápagos algae with emphasis on seasonality.

Information on the taxonomy of the benthic algae of the Galápagos Islands is available. Silva (1964) reported 311 species with 30% endemism. Velasco (1986 unpubl.) reported 400 species with 40% endemism. The biogeographical affinities of the flora have been determined.

Silva and Santelices and Abbott recognized Panamanian temporates, endemics, cosmopolitan and anti-tropical components to the flora. Prescriptive ecological studies have given baseline information on the distribution of many of the more common benthic algal species.

Needed information for management decision making for coastal areas in the Galápagos Islands include:

1. Productivity regions and biomass studies in upwelling and in areas of increasing human activity.
2. Relationship between herbivores and algal species.
3. Seasonal information on the distribution and abundance of common benthic algal species.
4. A centralized compilation of literature on benthic marine algae of the Galápagos Islands including both botanical and zoological (herbivore) studies. This compilation should include published articles and unpublished reports.

Immediate research needs for the management of the resources are:

1. Studies on seasonality of the benthic flora.
2. Studies on biomass and productivity of benthic primary producers emphasizing the more common species (encrusting coralline algae).
3. Studies on interactions between herbivores and benthic primary producers. Some of the more common herbivores including iguanas, sea turtles, Damsel fish, other fish species, Sally Lightfoot crabs, Ecdaris and other urchins, gastropods and chitons, to mention a few. Many of these herbivore species are part of the attraction for tourists in the coastal zone.

The greatest concern in developing the marine resources reserve of the Galápagos Islands is to preserve the abundance and diversity of marine organisms, and marine dependent organisms under increased human activity. Human activity is mainly increasing in coastal areas. Negative effects on benthic primary producers will in turn have negative effects on herbivores and eventually the entire food web. Therefore, there is a need to increase the amount of baseline information on this group of organisms especially in areas projected to have greater amounts of human activity in the future.

Discussion

Arthur Gaines: Aren't introduced species of algae a problem? Because the flora is rich in endemic species could this mean extinction of local species if an introduced alga got established? Laurie showed that introduction of an inedible algae species during El Niño caused dissemination of the marine iguana population.

Gary Kendrick: I don't believe that introduced species are as much of a threat as disturbance associated with human activity in the area. Most devastating introductions of species have occurred in higher latitudes.

Gerry Wellington: To clarify Gary's comments, I would like to say that competition is a greater component in the structuring of communities in temperate latitudes than in tropical latitudes. This is partly because herbivory is supposedly more intensive in tropical latitudes.

Characterization of the Marine Biota and Principal Habitats of the Galápagos

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Within the marine environment proper of the Galápagos Islands there exists a diversity of habitats (e.g., rocky shore, sandy beaches, mangrove lagoons, coral reefs) which harbor an unusual mixture of temperate, subtropical and tropical marine organisms. This unlikely assemblage, at an equatorial location, is largely due to the unique hydrographic conditions surrounding the islands. The convergence of distinctly different water masses, and the establishment of their biotas at a distant island location is unparalleled elsewhere in the world. Presumably, isolation has lead to the formation of marine communities that appear to be structured and organized quite differently from mainland counterparts.

The uniqueness of the Galápagos marine environment can be characterized by the following (Wellington 1975):

1) **Highly diverse and abundant biota assemblages** which are the result of several key factors. First, as mentioned above, the oceanographic setting is unique (Figure 1). Representatives of organisms derived from tropical (Panamic) and subtropical (Mexican) eastern Pacific provinces (Figure 2) arrived via the Panama Current which flows considerably southward during El Niño events. The warm temperate representatives of the Peru/Chilean region have invaded Galápagos from the westerly flow of the South Equatorial Current fed by the Peru Oceanic and Coastal current systems. Representative species of the Western Pacific biota have probably reached the Islands indirectly from other eastern Pacific islands (e.g., Cocos and Clipperton Islands) which are more directly situated in the path of the North Equatorial countercurrent.

Although the easiest and most direct avenue of dispersal to the Islands is from the south, the majority of the biota undoubtedly reached the Galápagos via the seasonal intrusion of warm water out of the Panama Bight. In general, however these currents flow strongest when reproductive activities are minimal along respective coastlines (Abbott, 1966).

Figure 1. Oceanographic and atmospheric characteristics of the Eastern Tropical Pacific Ocean.

Figure 2. Map showing the Eastern Pacific Tropical and Subtropical Provinces.

Secondly, the high diversity of biota is related to the great diversity of habitats (Table 1) which is a combined result of the wide variation of structure and composition of basaltic and carbonaceous substrates exposed to a range of wave action. And third, the large island mass (14,000 Km²) yields a coastal area at least two orders of magnitude greater than that found for other specific islands.

Table 1. Principal Coastal Marine Habitats in the Galápagos (compiled by F. Arcos)

-
- Nearshore habitats
 - Rocky shore (lava and tuffa substrates)
 - Intertidal and subtidal habitats
 - Boulders
 - Pahoehoe and AA lava
 - Vertical walls
 - Cryptic habitats (tunnels and caves)
 - Sandy beaches
 - Protected pocket beaches
 - Exposed open beaches
 - Mangroves
 - Lagoons
 - Hypersaline
 - Open
 - Coral Reef
 - Offshore habitats
 - Submarine banks
 - Neritic Oceanic
 - Pelagic Oceanic
-

2) **High rates of endemism.** This phenomena results from the relative isolation of the island biota from the continental biota. Furthermore, endemism may result in part from a mismatch between timing of reproduction and current flow patterns that tends to reduce gene flow by restricting the number of immigrants from mainland populations. This, compared with a more diverse physical environment, may have promoted genetic divergence (speciation).

3) **Inter-island regionalism.** This is the result of the association of distinct biotas in water masses representing different temperature regimes (Figure 3). The two most distant zones are the northern (Zone 3) and western sectors (Zone 5). The seasonal fluctuation of the North Equatorial Front, which separates tropical and subtropical water masses, lies near the islands of Marchena and Pinta most of the year. Consequently these islands, in addition to Darwin, Wolf and Genovesa, tend to be inhabited by a high proportion of tropical species. Macrophytic algae are essentially absent here, probably due to lower nutrient availability and intense grazing by tropical fish algivores. In contrast, the western and southern (Zone 2) sectors are influenced by the Equatorial Undercurrent which forces cool nutrient laden water to the surface (Figure 4). The dominant fish fauna in shallow water is decidedly from the warm temperate regions of South America (e.g., *Bochianus ectancheri*, *Oplegnathus insignis* and *Noxilosus latifrons*). These species occur abundantly in shallow water in these regions, but are also found in lower densities elsewhere in the Islands just below the thermocline. Earle (1980) has also noted a submergence phenomenon for many warm temperate algal species in the Galápagos.

Figure 3. Sea surface temperature zones in the waters surrounding the Galápagos Islands, defined by Harris (1969). The western zone (5) and southern zone (2) are subject to cool water conditions; zone 3 is generally more tropical and thus warmer than the other zones. Zones 1 and 4 are characterized by moderate temperature variations. Compared to zone 1, zone 4 tends to be slightly cooler during the dry season (June to December). (from Wellington, 1984).

Figure 4. Bathymetric chart of the archipelago showing the main flows of the east-going Equatorial Undercurrent (schematized by arrows) and the location of the most prominent upwellings (shaded areas). Sounding in fathoms. (From Houvenaghel, 1978).

In many places, especially along wave exposed shorelines, macrophytic algae are rich and abundant. With respect to invertebrates, the most striking example of regionalism is the shallow water urchin, *Caenocentrotus gibbosus*. This species is only abundant in the western sector; elsewhere it is replaced by the tropical species *Echinometra vanbrunti*. Hermatypic corals are scarce but the nonsymbiotic, ahermatypic fauna is rich.

The central zones (1 and 4), comprising the east coast of Isabela, Santa Cruz, and Santiago undergo moderate seasonal fluctuations. This area contains a mixture of faunas dominated by eurythermic elements of the Mexican, Panamic and Peru-Chile Provinces, as well as a distinct Galápagos endemic component.

It should, however, be emphasized that these patterns are not static. The distribution and abundances of many species undergo marked seasonal changes, particularly the algal communities. Moreover, severe El Niño events, such as occurred in 1982-83, result in dramatic alterations in the biota. Unfortunately few of these dynamic processes have been documented in a quantitative manner (see Robinson and del Pino 1985).

4) **Ecologically novel biotic assemblages**, such as the occurrence of coral reefs adjacent to diverse temperate algal communities which occurs in only a few other places elsewhere in the world (e.g. western Australia). Many of the benthic communities in the Galápagos give rise to interesting ecological and biogeographical questions. For example, the conspicuous absence of common mainland indicator species in the intertidal zone, such as the barnacle (*C. thamalus*) and the palmonate gastropod (*Siphonaria*), have not been adequately explained, particularly since Cocos Island is only 400 miles from the Galápagos (Wellington 1975, 1984). Examples of similar enigmas can be found in virtually every marine community in the Galápagos.

To summarize, the Galápagos are highly varied and are best characterized as representing a mosaic of species and community distributions that vary temporally and spatially with intra- and inter-annual periodicities. While we have a general picture of the composition of the biota and a feeling for the diversity of habitats and community types, we understand very little about the physical processes that control patterns of distribution and abundances, and even less about the importance of biological interactions.

Suggestion for future research efforts:

A literature update on the taxonomic studies of the Galápagos marine biota would be useful for scientists interested in working in the Galápagos, and could aid in formalizing management guidelines to define and protect sites or habitats with unique biota. To some extent such efforts have been initiated by recent computer inventories (Simkin - CDF and WHOI).

Since original efforts to characterize the Galápagos marine environment (Wellington 1975), few studies have quantitatively expanded on this knowledge. With the exception of the comprehensive studies conducted by Glynn and Wellington (1983) on coral communities and coral reefs, we have very little, if any, quantitative data for other habitats.

The scientific value of obtaining some quantitative data of representative habitats is highlighted by the recent biotic disturbance resulting from the 1982-83 El Niño event. From our work on coral reefs, we have been able to quantitatively evaluate the magnitude of this perturbation in terms of coral death and reef erosion (Glynn, personal communication). It will provide tremendous insight into the role of natural disturbances in this region. Although we recognize that other types of communities were affected to a similar degree, our efforts to document this impact and follow recovery are hampered by a lack of quantitative information. To remedy this problem, we recommend that baseline data be collected from a number of habitats over as wide a geographic range as possible. Obviously, such a task could involve tremendous effort and expenses. However, in spite of the financial and logistical constraints, at least a modest effort should be initiated towards achieving this goal.

We recommend the following projects:

1) Establishment of a series of baseline transects at 3 to 4 localities over as wide a geographic range as possible. At each of these locations, efforts should be made to encompass as many habitat types as possible including the intertidal zones down to a depth of 5-10 m. The precise details for sampling, and locations and types of habitats to be represented, would require careful consideration in order to maximize their potential value for statistical interpretation.

For these surveys to be practical and provide any useful information, attention and effort should focus primarily (if not exclusively) on taxa that are conspicuous and/or reasonably well known taxonomically (e.g mollusks, fish, corals, etc). Presumably, changes in diversity, abundance and distribution that occur within these groups will also reflect similar changes in other groups as well.

We envision that this task will initially require a extensive effort; however, once established, photographic sampling techniques could be used to evaluate major changes in the biotic composition of assemblages of sessile communities. Other methods would be required to sample organisms associated with sediments. Visual techniques would be needed to evaluate mobile organisms such as fish.

2) A general inventory of habitat types providing some quantification of distribution and abundance. This inventory could be facilitated using low altitude aerial photographs. Information such as the distribution of sandy beaches, rocky intertidal shores, mangrove communities and coral reef structures could be readily obtained. Some of this work has been conducted for mangrove distribution and sandy beaches (i.e., identification of turtle nesting sites).

3) As pointed out above, the biotic regionalism that is uniquely characteristic of the Galápagos waters, has only been qualitatively described. Further qualitative and quantitative documentation needs to be done to characterize this phenomena. The results gathered from the baseline studies proposed above could be compared with large scale sea surface temperature and phytoplankton (primary production) mapping now possible with remote sensing technology described by Dr. Steve Ackleson elsewhere in this report.

In addition to describing the resources in more detail, there is a need to gain information on functions and processes which occur in these marine environments. For example, targeted recruitment studies using virtually any organism (barnacles or fish would be good examples since there is comparative data available from other systems in the tropics) would provide potentially valuable information concerning the relative importance of currents and patterns of productivity in Galápagos waters. Results from such studies may indicate the degree to which populations (and communities) are susceptible to natural disturbance or human exploitation.

Lastly, studies on community structure and organization should be promoted. Investigations such as those conducted by Glynn et al. (1979) and Glynn and Wellington (1983) reveal that coral

communities in the Galápagos are regulated by very different forces than their mainland counterparts. Community studies similar to those recently conducted on intertidal shorelines along the Pacific side of Panama (Menge and Lubchenco, 1981) could be repeated in the Galápagos to determine the extent to which tropic mainland intertidal communities are structured by similar factors as those found in mainland studies.

The overall goal here, from a scientific point of view, is to identify the dynamic processes that shape insular marine ecosystems. From a management viewpoint, results from such broad-based studies can be used to identify potentially critical features of the resources (e.g. habitats with unique biota, or processes that are essential to sustaining relationships between populations within communities), that may warrant attention.

Research opportunities

Obviously the Charles Darwin Research Station (CDRS) in collaboration with Ecuadorian institutions such as the Oceanographic Institute of the Navy (INOCAR), the National Fisheries Institute (INP), and others should be directly involved in establishing baseline data from surveys and monitoring programs in Academy Bay. Preliminary results could serve as a model for developing a broader program. Financial support and manpower to gather the initial archipelago-wide database could possibly be obtained by soliciting such groups as Earthwatch, UC Educational Extension Program, CEDEM, Semester-at-Sea, etc.

A likely source of support for process-oriented studies is the National Science Foundation, Program for International Studies. This program considers funding for joint US/Ecuadorian investigative efforts.

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Galápagos Coral Reefs

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Corals and coral reefs are an important marine resource for tourism, fisheries and sciences. Coral reefs of the Indo-Pacific have shown remarkable resilience in the face of natural disturbance such as outbreaks of *Acanthaster planci*. The rapid recovery of Indo-Pacific reef ecosystems results from a combination of factors that include rapid growth, high recruitment rates, and the maintenance of the integrity of the reef structure. In the Galápagos, reefs that are disturbed would have a longer recovery time because of relatively low growth rates, low recruitment, high degree of bioerosion, and repeated thermal stresses. Therefore, the reefs of the Galápagos represent a potentially more fragile ecosystem than those of the Indo-Pacific. Because Galápagos coral reefs have potentially slow recovery rates after a disturbance, they require special attention in the management plan.

In the Galápagos, human disturbance of the coral reef environment has apparently been slight. It seems almost paradoxical that any area in the world with such natural beauty, intrinsic interest, and high popularity can still claim a marine environment of virtually pristine quality. This circumstance is not fortuitous, but is due in large measure to a model system of conservation and education promoted by the Charles Darwin Foundation for the Galápagos Isles and the Galápagos National Park Service of the Government of Ecuador (Glynn and Wellington 1983).

Charles Darwin was perhaps the first to collect a Galápagos coral for scientific purposes in the Galápagos. Unlike the pivotal role the Galápagos played in his theory of evolution, the islands did not enter into Darwin's ideas concerning the formation of coral reefs and atolls.

Unlike Indo-Pacific reefs that often fringe an island, Galápagos reefs are small, localized communities, and their size and isolation delayed their discovery. In the Galápagos, water temperature plays an important role in determining the distribution of reefs and the rate of development. Seasonal pulses of cold, upwelling water, concentrated in the southwestern sector of the archipelago, largely restricts reef growth to the north eastern and eastern portions of the islands (Glynn and Wellington, 1983). The small size of Galápagos reefs may partly be the result of low recruitment rates. In the face of low recruitment, corals are unable to colonize surrounding substrate in great numbers. Instead they reproduce asexually through fragmentation. Also, the high rates of bioerosion, especially from the feeding activity of the club spined sea urchin (*Eucidaris thouarsii*), removes much of the calcium carbonate from the reef framework preventing a more rapid accumulation of reef mass. This is especially serious after a disturbance that kills the corals or slows carbonate production. In this case removal rates could exceed the rate of carbonate production. If this relationship were to continue for a long enough period then carbonate deposits would be removed and reef development would have to start from scratch.

Therefore, a long successional and building process would have to occur to return the reef to its previous state.

It was long thought that cold upwelling water alone restricted Galápagos reef growth. However, during the 1982-83 El Niño-Southern Oscillation (ENSO) event, elevated temperatures in the eastern Pacific severely damaged Galápagos marine life (adding a new climatic factor into the equation of Galápagos reef development). This El Niño killed vast numbers of corals in the Galápagos and nearly caused the extinction of *P. damicornis* there. According to Dr. Peter Glynn, such severe El Niño events may be important forces in structuring the marine communities of the eastern Pacific. Indeed, the small size of Galápagos coral reefs may reflect the repeated thermal stresses suffered during El Niño years.

The impact of El Niño events on eastern Pacific marine communities depends on the frequency with which the events occur in relation to the lifetime of the communities. However, the long-term record of the periodicity and ferocity of ENSO events is poorly known, and our understanding of marine and terrestrial community development under El Niño stresses thus remains incomplete. More importantly, a long-term record of El Niño events would help planners to prepare for future ENSO events; the negative effects of the El Niño warming were not limited to marine communities of the eastern Pacific; they include worldwide climatic changes that resulted in the loss of billions of dollars and thousands of lives.

Research at Urvina Bay (Isabela) conducted by Colgan and Malmquist (U.C. Santa Cruz) and Smalley (University of Hawaii) shows the factors associated with coral reef development. Around March 1954, magma beneath Volcano Alcedo suddenly rose, thrust the shoreline of Urvina Bay 1.2 km seaward, and exposed several square kilometers of its marine community.

Although the eight hermatypic (reef-building) coral species that inhabited Urvina Bay occur in nearly every subenvironment on the uplift, they are concentrated in only ten locations. Three species, *Pavona clavus*, *Porites lobata*, and *P. damicornis*, have alone produced five monospecific reefs. At first thought, these monospecific stands might be taken to reflect distributional constraints brought about through competition or genetics. But, with the exception of a few cases where *Pocillopora* overgrew the branching coral *Psammocora* or massive colonies such as *P. lobata*, competition between corals is not apparent. Moreover, as defined by inferred water depth and current exposure, most of the corals lived in similar environments. Without any outstanding environmental constraints on their distribution, the segregation of corals on the uplift may simply reflect chance settlement.

Because parts of the Galápagos are normally bathed in relatively cool waters, the islands are a marginal reef-growing environment, and, once coral larvae settle there, the harsh conditions may limit their success at further sexual reproduction. We now have evidence to show that corals in the Galápagos compensate by reproducing asexually, through fragmentation and regrowth. For instance, counting of the growth bands of a giant colony of *P. clavus*, by Dr. Gerry Wellington, an Assistant Professor of Biology at the University of Houston, shows this coral to be at least 350 years old. Nevertheless, except for fragments at the coral's base, there are no other

individuals of *P. clavus* within 50 meters of this coral. Thus, for a third of a millennium this coral grew and survived, but apparently could not sexually reproduce. Because asexual reproduction through fragmentation limits the ability of corals to spread, Galápagan corals remain clustered in the random areas where colonization originally occurred.

Fragmentation, and hence asexual reproduction, of corals in the Galápagos is accelerated by bioerosion. At Urvina Bay, bioeroders are common, ranging from fishes to sponges, but the most conspicuous eroder is the club-spined sea urchin (*Eucidaris thouarsii*). Coral colonies on the uplift are often so heavily infested with *Eucidaris* borings that they are nothing but thin shells arching over a hollow interior. But like the saplings that spring from the stump of a fallen tree, the fragments produced by bioeroders commonly fall around the perimeter of the parent colony, where they continue the colony's growth. Many of Urvina Bay's corals apparently reproduce most successfully through this type of asexual fragmentation (Colgan and Malmquist, 1987).

The greatest threat to the Galápagos coral reefs would be a weakening of the authority of the Charles Darwin Research Station and the Galápagos National Park Service. They have provided and hopefully will continue to provide the conservation planning and educational guidance that has protected this fragile ecosystem with an increasing local population and an accelerating tourist industry. The Charles Darwin Research Station and the Park service are needed to assure a continuing high level of environmental quality.

Added stress to the Galápagos coral reefs from tourist uses should be avoided to the greatest extent possible. Increased tourism and the concomitant increase in anchoring could damage a coral community. Mooring buoys should be set-up at visiting sites to prevent the breakage of coral colonies. The Charles Darwin Research Station has already responded to the increased interest in the marine environments by gearing guide courses towards protecting submerged and uplifted reef communities.

Research of coral reefs should continue. Peter Glynn's work on coral reef community recovery after the 1982/83 El Niño disturbance will determine how and at what rates Galápagos reefs recover - essential information for management planning. Likewise, the work at Urvina Bay needs to continue to obtain the historical perspective of reef development. Furthermore, determining the frequency and magnitude of El Niño disturbances is of utmost importance because of the historical as well as recent implications that the El Niño event has on reef development. A long-term historical El Niño record is absent from the literature.

Urvina Bay may well provide us with this sorely needed record of El Niño events. Because El Niño events change the temperature of the sea, they also predictably alter the ratio of stable-oxygen isotopes that corals incorporate in their skeletons during growth. By examining the isotopic signal recorded in the calcium carbonate (CaCO_3) skeleton of a giant *P. clavus*, the thermal condition of the ocean at the time of the coral's growth can be reconstructed. A 4 meter core from this coral was extracted. The core represents at least 350 years of time, and extends the record of El Niño to roughly 1600. The isotopic analysis of the core is being done by Dr. Gerry Wellington and by Dr. Rob Dunbar, an associate Professor of Geology at Rice University.

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Marine Dependent Organisms

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Maritime Species

If one were to make a simple inventory of the species of Galápagos vertebrates likely to be observed at the numerous visitor sites throughout the archipelago, that compilation would be strongly biased toward organisms intimately linked between the terrestrial and marine environments. Such maritime species include the Galápagos sea lion, *Zalophus californianus wollenbacki*, Galápagos fur seal, *Arctocephalus galapagensis*, flightless cormorant, *Nannopterum harrisi*, Galápagos penguin, *Spheniscus mendiculus*, and Marine iguana, *Amblyrhynchus cristatus*. The list also would include many resident species breeding in the Galápagos, but also having much larger geographic distributions through other oceanic islands in the tropical Pacific and/or coastal areas of the American continent. For at least one of these resident species, the Hawaiian Petrel, the Galápagos Islands are critical habitat, as this seabird faces threats caused by introduced predators and habitat destruction in both the Hawaiian and Galápagos Islands. White, Eppler and Gilbert (1972) provide a good synopsis of the many marine dependent seabirds, mammals, and reptiles present in the Galápagos, which includes resident and migratory species.

In general, our state of knowledge of the terrestrial needs of most Galápagos Maritime species is substantial. Efforts to obtain estimates of population abundances, inter-island distributions, studies of reproductive biology and behavior, and the interactions of maritime species and introduced predators in reference to conservation actions have been undertaken for many of the conspicuous maritime species. In contrast, knowledge of the requirements of these same species in the marine environment is not as good, though many studies in variation in population abundances and reproductive success of maritime species assume such changes are related to ocean variability and the distribution of food resources in the marine environment. How far such species may range in search of food, dietary relationships, and the role of natural variability in ocean conditions, and during El Niño phenomena, in population regulation has not been quantified for many maritime species, though some data exist for fur seals (Trillmich and Limberger, 1985) and marine iguanas (Laurie, 1985). A comparison of the ecology of maritime species present in the Galápagos and other oceanic islands might prove fertile ground for basic research into questions concerning island biology and ocean variability.

Marine Species

To many visitors of the islands, the presence of whales and dolphins in the archipelago augments their experience. At present we know only that they occur in the Galápagos. Whether certain

species may be considered permanent residents of the tropical eastern Pacific or whether some species regularly migrate to the islands from polar feeding grounds in order to calve or form mating groups in Galápagos waters is not known. The historical record of the importance of whaling in the Galápagos indicates the former abundance of cetaceans in the adjacent tropic upwelling ocean ecosystem.

It has been estimated that the level of endemism of Galápagos marine species found in the nearshore environment averages 25% across all taxonomic groups. Virtually no studies of this biota have been undertaken. What are their habitat requirements, population dynamics, community interrelationships, etc? Opportunities for basic research abound in the Galápagos due to the high priority management concern for conservation of endemic species in the Galápagos Marine Resources Reserve. Conservation is based on basic scientific information.

That a number of endemic species, such as camotillo (*Paralabrax albomaculatus*), bacalao (*Mycterperca olfax*), and vieja (*Semicossyphus darwini*) also form part of the artisanal fishery is noteworthy.

Management Considerations

In other areas of the world, conflicts exist between marine resource extraction and conservation needs of marine/maritime species. While the present artisanal fishery as it is structured in the Galápagos Marine Resources Reserve (GMRR) does not appear to pose any danger to marine/maritime species of aesthetic, scientific and touristic value, it is conceivable that future conflicts might develop which could be circumvented with careful forethought by members of the planning committee for management of the GMRR. With increased urban development and tourism, utilization of marine resources may become more intense. Given the importance of conservation in the GMRR there exists the unique opportunity for deciding, or determining the mechanism for deciding, what kinds of fishing methods are consistent with the conservation goals in the islands and providing appropriate legislation. The problem of entanglement in lost gear, drowning and ghost fishing are real management concerns in the Galápagos. Such experiences in other regions of the world usually exist before corrective action is taken. The ability to provide guidelines beforehand in the Galápagos is unprecedented anywhere in the world.

The presence of plastics in the marine environment is of worldwide concern, as accidental deaths by entanglement and ingestion (especially by sea turtles) are known to occur. Such material accumulates on the beaches of the Galápagos and remains there for long periods of time, thereby affecting the aesthetic quality of the shoreline. Conservation of sea turtles is of worldwide concern and the Galápagos now constitutes one of the largest breeding areas of green sea turtles. With increased tourism, the input of plastics in the marine environment is likely to increase. Without well-planned educational and financial incentive programs, strict regulations for handling these materials, and possibly the imposition of fines for noncompliance with regulations, these plastic materials will likely continue to plague the pristine nature of the Galápagos.

Discussion

Nancy Foster: When planning for management of a marine protected area (or species) one should anticipate potential conflicts, and design strategies to avoid, minimize, or resolve them lest they become serious problems threatening conservation objectives. The U.S. experience in Hawaii provides an example of the consequences of the lack of such planning: need for extreme management actions; loss of public support; increased enforcement expenditures; and a missed opportunity to communicate a conservation need.

A portion of the humpback whale population winters over and calves in the waters of the Hawaiian archipelago. Over the years enforcement observations and anecdotal information have indicated changes in whale behavior patterns. Animals have shifted from previous areas of concentration after an increase in boat docks, traffic and certain recreational activities such as the use of jet skis. Whales were observed modifying behavior or making sudden exits when approached head-on or rapidly with abrupt changes in engine idle or boat direction. Increasing whalewatching, general vessel traffic, research activity and reports of harassment resulted in issuance of guidelines for approaching whales. This code of "etiquette" was provided by the managing agency, NOAA. Unfortunately, the action came too late and without the basis of a comprehensive public education program to explain the need for adherence to such guidelines.

As a result, it became necessary, amidst increasing reports of harassment, to promulgate formal regulations that require a greater expenditure of public funds for enforcement and processing of violations, diminishing public support (for the agency) and good will and thereby a loss of conservation benefit to the species in question.

The lesson is to begin, before serious conflict develops, with a sound public education effort. Such an effort should focus on the need for certain constraints when using protected resources and should be built into the planning phase of any conservation program.

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Endemism in Marine Organisms

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Endemism is an inherent aspect of most island marine biotas - thus the Galápagos is not unique in this regard. However, for its size and relative proximity to mainland shore (compared, for example, with the Hawaii Archipelago), it probably has a greater number of endemic forms relative to most other island systems. It certainly has a richer diversity of endemics than the other known eastern Pacific insular biotas (Malpelo, Cocos, Revillagigedo and Clipperton Islands).

A brief summary of the biogeographic affinities of the Galápagos marine biota shows a remarkably high rate of endemism (Table 1) ranging from 10-35% in the various taxa. This high variance may be due to phylogenetically-based differences in the propensity to speciate, or perhaps simply reflect a poor understanding of the taxonomic relationships. The best and most reliable estimate is found in the fish fauna (McCosker and Rosenblatt, 1984), which shows about 17% endemics. If this is conservative, then the fauna is very unique.

Table 1. Summary of biogeographic affinities of the Galápagos marine biota (based on references compiled by Wellington 1975, 1984). Values represent percentage of total reported species.

Biogeographic region	ALGAE	CORALS	CRABS	MOLLUSKS	ECHINODERMS	FISH	OVERALL AVERAGE
Galápagos endemics	35	23	22	35	10	17	24
Insular endemics	<1	0	3	2	6	2	2
Panamic	40	4	70	59	75	58	51
Temperate (Chilean/Peruvian)	4	0	19	0	2	7	6
Western Pacific cosmopolitan	10	45	8	9	20	14	17
Atlantic	14	10	7	4	<1	1	6
Total species	333	42	117	399	82	309	1282

Intrinsically, endemics are very interesting since they allow us an opportunity to study evolution in marine systems. Are the mechanisms of speciation different for marine organisms? In marine organisms, with a potential for wide dispersal, are the mechanisms of speciation different from those of the terrestrial environment (see Miller, 1966)? The conventional wisdom holds that endemics are less agile and thus susceptible to reduced gene flow: Is this true for species in marine environments? There are many questions which Galápagos research could help to resolve.

I will attempt to outline some of the questions and the methods currently available to study marine endemism in the Galápagos.

Suggested Scientific Studies

While there is little question that the Galápagos harbors a unique biota, it is not entirely clear whether the high rate of endemism is over- or under-estimated. For some taxa the systematics is far out of date and in need of appropriate revision. In other cases, major groups have simply not been examined either in the Galápagos or along the mainland shores (Peru to Panama). Some intensive systematic work is now being conducted in the Gulf of Guayaquil (by INOCAR) but these efforts need to be extended to the Galápagos. With the possible exception of the fish fauna, we simply cannot say with a high level of certainty just how unique the Galápagos is. More comparative studies need to be conducted.

In addition to using classical taxonomic techniques (eg. morphological analysis, and protein electrophoresis), there are now several new methods that can be used to establish the uniqueness of Galápagos species. For example, recent advances in mitochondrial DNA analysis now enables us to evaluate times of divergence between two populations (Wilson et al., 1985). This genetic technique has a high degree of accuracy for separations that occurred 1 million years ago. Given the age of the Galápagos, and other related Eastern Pacific Islands (three million years), this technique could be used effectively to investigate the evolutionary history of the marine endemics of the Islands.

Once the taxonomic relationships become better known and divergence times established, we will be in a position to ask questions regarding the mechanism about insular evolution using the Galápagos as a model system. Given the generally high dispersal potential of most marine organisms, what are the mechanisms that foster and maintain endemics?

We can ask whether these patterns are simply a result of persistent isolation (the general explanation given for terrestrial evolution). This hypothesis can be addressed through life-history studies that may reveal key differences between endemics and non-endemics. For example, is there a pattern of low larvae dispersal for endemics? In addition, recruitment studies could reveal the degree to which populations disperse and thus the potential for isolation.

Alternatively, there may exist unique interactions that could result in intense natural selection (vis a vis the terrestrial paradigm). Under this scenario, recruitment from outside sources continues

to occur, but strong selection maintains a disproportionate number of local adapted genotypes. In addition, historical factors may explain the existence of some endemic forms. The presence of some endemic species whose closest related ancestors are restricted to the Atlantic Province may represent a relic population with its eastern Pacific ancestors having gone extinct along mainland shores some time in the past (McCosker and Rosenblatt, 1984; Wellington, 1984). This situation is analogous to the persistence of many terrestrial species whose ancestors went extinct on the mainland subsequent to becoming established on the Islands.

This is a tremendously interesting marine biota of which we know very little. There are a few places in the world that offer the opportunity for understanding the mechanism responsible for the evolution of insular marine species. Those interested in marine biogeography should be made aware of the uniqueness of this situation and we need to promote this type of research in the Galápagos Islands.

Regarding management implications, since we know little about the distribution or life-history of most species, it is difficult to identify potential situations where management policies need to be considered. However, we know that some endemic populations may be susceptible to perturbations. For example, the blind cave fish endemic to the Galápagos live in a restricted habitat with perhaps very limited distributions and abundances (van Moll, 1967).

It should be pointed out here that the bacalao (*Myctoperca oftax*) is an insular endemic found only in the Galápagos, Cocos and Malpelo Islands. Even though extensive fishing seldom leads to extinction of non-mammalian marine species, we do not know how geographically isolated populations may be affected when local populations are severely reduced. Recent observations of missing year-classes in the bacalao population, associated with the 1982-83 El Niño, could have important ramifications to population persistence (T. Rodriguez and G. Reck, personal communications).

In summary, the Galápagos marine biota contains a high percentage of unique species. What accounts for this phenomenon is not known. Future studies are needed to:

- 1) clarify the extent of this endemism, particularly in groups where the taxonomy is poorly defined. Comprehensive and comparative (mainland versus Galápagos) systematic studies are needed to fully evaluate the taxonomic relationship of Galápagos species with the eastern Pacific biota,
- 2) understand the mechanisms of speciation in marine insular environments. Studies of the differences in life-history traits of endemic versus non-endemic species may reveal the critical factors responsible for the formation and maintenance of endemic populations, and
- 3) define management policies to protect unique species. This will require identifying endemic species whose populations are restricted to geographically limited habitats that are potentially subject to human-induced perturbations.

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Introduced Species and the Galápagos Marine Resources Reserve

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The establishment of the Galápagos Marine Resources Reserve provides a unique opportunity to incorporate concerns about introduced species into the initial stages of a management plan. There is no other marine reserve or park that has addressed this question at an early planning stage.

Introduced species (human-mediated dispersal) and range expansions (natural dispersal) are both forms of biological invasions (Figure 1). Both may be followed by diffusion or spreading. Range expansions may lead to evolution of new species in isolation (such as on islands). Indigenous species, as opposed to introduced species, are those that occur naturally in the region in question, and these may be native or endemic. Finally, a species whose history cannot be defined clearly is cryptogenic. These terms, and certain synonyms, are defined in Figure 2.

Figure 1. Forms of Biological Invasion.

Figure 2. Glossary of terms used to describe Biogeographic Origins of Animals and Plants

<u>Range Expansion:</u>	A species naturally dispersing into a region where it did not formerly exist.
Synonyms/related terms:	natural immigration, natural invasion, self-colonization, self-introduction.
<u>Indigenous:</u>	A species naturally found in the region in question, either occurring in the region and nowhere else (<u>endemic</u>), or occurring in the region and elsewhere (<u>native</u>).
Synonyms/related terms:	aboriginal, autochthonous, endemic, native, natural.
<u>Introduction:</u>	A species transported by humans into a region where it did not exist in historical times.
Synonyms/related terms:	acclimatization, adventive, alien, allochthonous, exotic, foreign, immigrant, importation, invader, naturalization, nonindigenous, non-native, synanthropic, transfer, transplant, weed.
<u>Cryptogenic:</u>	A species that cannot be clearly recognized as either indigenous, an introduction, or a range expansion.

Well-developed global criteria have been used to distinguish introduced from indigenous species. These criteria are based on evidence derived from systematics, biogeography, history, archaeology, paleontology, and genetics. Other evidence is ecological: a strong association with a known

Well-developed global criteria have been used to distinguish introduced from indigenous species. These criteria are based on evidence derived from systematics, biogeography, history, archaeology, paleontology, and genetics. Other evidence is ecological: a strong association with a known dispersal mechanism (a "typical" fouling organism of boat bottoms newly appears in a harbor, for example), or a distribution restricted to often human-disturbed environments (harbors, estuaries, etc.).

Many of these criteria are difficult to apply, however, in poorly studied areas, in areas where little historic or prehistoric data are available, and/or in areas characterized by a complex pattern of oceanic currents which may naturally transport into a single region propagules (such as larvae) from many regions. All of these conditions apply, to a varying degree, to the Galápagos Islands (Glynn and Wellington, 1983; Wooster and Hedgpeth, 1966; Perry, 1984). Nevertheless, species of marine invertebrates and algae that would be "candidates" for being introductions in the Galápagos Islands include species that 1) have "unusual" distributions (such as California and Galápagos, or Japan and Galápagos -- i.e. source regions other than the Eastern Pacific and Indo-Pacific Oceans or more rarely, other than a potential Tethyan relict); 2) are known ship-fouling species regarded as "classic" introductions to harbors, and 3) are not likely to be dispersed by currents (no planktonic larvae) nor by rafts or floating algae (e.g., species occurring only on rocks, or only in soft sediments). In all species, regardless of the region under study, the older the possible introduction, the harder it will be to fully distinguish 'natural' from 'human-induced' patterns of distribution.

It is useful to ask, especially in insular environments, why distinguish "introduced" marine species from "natural" invasion (range expansion) processes? Kramer (1984) has remarked that determining how organisms got to the Galápagos has been an "entertaining pastime" for biologists. Is it a purely academic exercise, or are there other values? And, more directly, could one not argue that all species in the Galápagos are really invaders anyway? What does it matter whether species are introduced by winds, or by currents, or by humans? Do not the natural colonization processes (and natural variations on normal processes, such as El Niño, constantly modify and change the biota anyway?

Detailed knowledge of what species are introduced and what species are native are extremely valuable for a number of reasons:

Introductions lower the degree of natural isolation by bringing species in that would not and could not naturally colonize the Galápagos Islands. A working assumption here is that after three million years, most species that could get to the Islands naturally would already be there. Introductions further alter the evolutionary balance and responses of the natural communities they enter:

DISPERSAL

- - El Niño and other natural processes - 3 million years?

- - Introduced species (including man) - 300 years?

--> slower evolutionary changes

----> faster ecological, alters rate and direction of evolutionary processes

Finally, and of particular importance on the Galápagos Islands, introduced species that remain unrecognized, obscure the interpretation of how such insular marine communities evolved, confounding natural dispersal processes over geological time with more rapid human-mediated dispersal processes over historical time. We may thus ask what processes have yielded the patterns of marine organic diversity we see today in the Islands; an inability to distinguish natural origins from anthropogenic origins compromises any interpretation about the age and thus the evolutionary history of Galápagos marine communities.

Marine, Maritime, and Terrestrial Introductions

There are two primary areas of interest relative to introduced species and a marine reserve: 1) marine introductions and 2) terrestrial introductions that impact marine species. While the present discussion is largely confined to the former, the latter is of course a critical element of understanding for a marine reserve management program. Examples of terrestrial introductions directly or indirectly impacting marine organisms on the Galápagos Islands are well-known, and include the following interactions (the actual list is much longer!):

Galápagos penguin	}		
Flightless cormorants			dogs
Hawaiian Petrels			cats
Marine iguanas			rats
Lava lizards			pigs
Green Turtles			humans

Discussions of some of these interactions are found in Eckhardt (1972), Haeck (1984), Kramer (1983, 1984), Laurie (1983), Sitwell (1983), and de Vries and Black (1983), as well as many issues of *Noticias de Galápagos*. For some of these predator-prey relationships between introduced terrestrial mammalian predators and their native prey, quantitative data are available (Laurie, 1983, Kruute and Snell, 1981, and Laurie, continuing studies), while for other relationships only anecdotal, qualitative data are available. There is as yet no synthesis available bringing together the data that are known, so that "which predators consume which prey" items remains scattered through numerous published and (often) unpublished reports. There are also little or no historical data available. Thus, while most of the feral predators of concern were introduced in the 18th and 19th centuries, the first scientific investigations do not commence until the late 20th century. Therefore, we must ask what phenomena are really being studied. Finally, there remains a difficult-to-understand balance between natural population depressions that continually recur (such as the impact of El Niño phenomena on the marine algae and thus the marine iguanas) and induced population declines that may be unidirectional unless conditions are altered (such as the impact of potentially removable dogs, pigs, rats, and cats on the marine iguana). Are there differential population rebounds if in one case El Niño is relaxed or feral predators are eliminated? Are there reversible versus irreversible processes? Little understood too are the secondary and tertiary effects of the impact of introduced species on animals such as the marine iguana. If, for example, marine iguanas are eliminated by cats from a given island, do the former prey (algae) of the iguana respond to this predator removal? Clearly, much remains to be learned here.

Mechanisms of Dispersal of Marine Organisms by Humans

Humans have moved marine organisms -- invertebrates, fish, algae, seagrasses, and maritime plants -- around the world intentionally and accidentally for centuries. The major mechanisms are shown in Figure 3. The oldest and most pervasive has been the role of ships in moving organisms attached to their hulls (and, when there were wooden vessels, in their hulls). It may be said that in general, wherever ships have been consistently over a long period of time, and where the biota are reasonably well known, species introduced by ships are known.

Figure 3. Dispersal Mechanisms of Marine Organisms.
 (Other than by ocean currents, birds, or marine mammals)

I. VESSELS (SHIPS)

- Fouling and boring organisms
- Ballast: sand, rock, and strand (shoreline)
- Ballast: seawater
- Water wells: bait or fish holding
- Dunnage (cargo packing materials)

II. OTHER MARITIME ACTIVITIES

The movement of:

A. SEMI-SUBMERSIBLE EXPLORATORY DRILLING PLATFORMS

- Fouling organisms
- Ballast: seawater

B. SEAPLANES

- Fouling organisms

C. LOG BOOMS

- Fouling and boring organisms

D. NAVIGATION BUOYS

- Fouling organisms

III. FISHERIES AND MARICULTURE

A. OYSTERS

- Intentional and accidental releases
- Epibiota, Pathogens, Parasites
- Associated sediments and biota

B. OTHER SPECIES (fish, crustaceans, mollusks,
 polychaetes, including bait species)

- Intentional and accidental releases
- Epibiota, Pathogens, Parasites
- Associated sediments and biota

C. AQUARIUM TRADE

- Intentional and accidental releases
- Associated biota and pathogens

IV. SCIENTIFIC RESEARCH

- Intentional and accidental releases

V. INTEROCEANIC AND INTRAOCEANIC CANALS

We know little about how the dispersal mechanisms shown in Figure 3 relate to the Galápagos Islands, with the exception of shipping. Abbott (1966) noted in general terms that ships as a means of dispersal was a "possibility" that "cannot be excluded." Since at least the 16th century, many vessels of all types from around the world have visited and come to anchor at the Galápagos. These include whalers, sealers, fishermen, explorers, scientists, pirates, and the military as well as general cargo vessels and, in increasing numbers today, recreational vessels. While no formal maritime history of the Galápagos Islands has been written, numerous authors have summarized the general patterns. There has clearly been a vast potential for the introduction of exotic species by international ship traffic, ranging from the New England whalers to the California tuna boats to Japanese fishing vessels (Slevin, 1959; Hickman, 1985; Thornton, 1971). There appears, also, to be a very high potential that ballast -- especially in the form of sand, rocks, cast-up seaweed, and so on (all of the materials that would have weight and could be gathered from the shore) -- was released at the Islands. Did the whalers and others release ballast to fill their holds with hundreds of turtles? And at one time, timber (lumber) was exported to Guayaquil from the Galápagos, to the extent that large native trees have been largely eliminated in some regions on the islands (Wiggins and Porter, 1971). We may assume that at least some of the vessels left the mainland in ballast, eventually to off-load the ballast to be exchanged for timber.

Introduced Marine and Maritime Organisms on the Galápagos

As a result of several centuries of shipping, what marine species have been introduced to the Galápagos Islands? While the introduced terrestrial mammals, birds, plants and some insects are well-known, the potentially introduced marine organisms are poorly known.

I have assembled a list of possible introductions of marine and maritime organisms in the islands (Figure 4), along with a footnoted assemblage of expected introductions. This is the first such list and thus highly preliminary. An examination of the literature or authorities cited in Figure 4 reveals that a casual examination of the literature on the Galápagos Islands would yield no records of introduced marine species. There are likely to be other examples scattered through the diffuse Galápagos literature, but one over-riding conclusion is clear: few marine introductions are recognized, and the number of unquestionable introductions of those that are known is even smaller.

Figure 4. Marine and Maritime Organisms Possibly Introduced by Shipping to the Galápagos Islands.

TAXON or SPECIES	AUTHORITY/COMMENTS
CRUSTACEA:	
ISOPODA	
<u>Limnoria</u> sp.	Miller (1966): undetermined species
AMPHIPODA (Gammarids)	
<u>Hyale rubra</u> (group)	J. Chapman (Oregon State University, 1987, pers. comm.) "most abundant
<u>Erichthonius brasiliensis</u>	intertidal gammarids (Barnard, 1979) are either introduced or
<u>Amphithoe pollex</u> (group)	cryptogenic; biogeographic affinities of these are largely North
<u>Elasmopus rapax</u> (group)	Atlantic or Northwestern Pacific.
COPEPODA	
<u>Pseudodiaptomus</u> sp.	A. Fleminger (Scripps Institution of Oceanography, 1987, pers. comm.): probable ballast water introduction.
ANNELIDA: POLYCHAETA	
Spirorbids (small tube worms)	Bailey and Harris (1968): "Transport amongst growths fouling ships is another possibility" for introduction to Galápagos.
MOLLUSCA: BIVALVIA	
Teredinidae (shipworms)	Miller (1966): undetermined species in old boat hulls at Academy Bay.
CYPERACEAE: (sedges)	
<u>Cyperus brevifolius</u>	Wiggins and Porter (1971): littoral zone weed
<u>Eleocharis atropurpurea</u>	Wiggins and Porter (1971): littoral zone, Isla San Cristobal

Examples of categories of introductions to be expected:

- * Barnacles: Balanus amphitrite-group (including Balanus improvisus, Balanus amphitrite, and Balanus reticulatus)
- * Shore-dwelling (strand, maritime) insects, crustaceans, plants, and gastropods (melampids, assimineids), and some meiofaunal (interstitial) taxa [ballast releases]
- * Northeastern Pacific isopods and possibly other peracarids; [note amphipod complexities; analysis of other peracarid groups needed]

Why do we know so little of this phenomenon on the Galápagos, a phenomenon so well documented on other islands such as the Hawaiian chain (Carlton, 1987)? There are at least three major reasons:

(1) The marine biota on the Galápagos Islands have been the subject of comparatively few studies (Wellington, 1984). In particular, there are a few published studies of the habitats on the Galápagos where introductions may occur (jetties, docks, pilings, boats, anchorages, buoys, wharves, etc). Thus, perhaps there are more introduced species on the Galápagos, and they remain unrecognized.

(2) The Galápagos lie within a complex oceanographic regime that changes over time and that has created a natural biota of complex, mixed biogeographic affinities (these being largely Eastern Pacific, Indo Pacific, and apparently Tethyan derivatives). Thus, ship-borne introductions from these vast source areas would be potentially difficult to detect -- unless, as noted earlier, taxa not likely to be transported by any natural means are involved.

(3) For many tropical and subtropical invertebrates and algal groups, the state of knowledge of their systematics and biogeography remains very poor. Many species regarded as "panropical" or "tropicopolitan" in fact doubtless represent lumping of several (or more) species into one morphologically similar taxon. The taxonomy of numerous groups -- small crustaceans, polychaetes, coelenterates, sponges, tunicates, filamentous algae, etc. -- all well-known ship fouling taxa, remains to be worked out for the Galápagos. Thus, if ship introductions have occurred, they may be obscured by taxonomy.

Conversely, it may be argued that one reason few marine introductions have been reported for the Galápagos is because few have actually occurred. At least two scenarios are possible here:

(1) ship-borne introductions cannot survive on the Galápagos (for example, for physical reasons such as temperature, lack of suitable substrate, or for ecological reasons such as competition, predation, or food requirements, and (2) despite the number of ships and the hundreds of years involved, there have not been sufficient multiple and massive inoculations such as are characteristic of large harbors (such as Guayaquil). If in fact there are few (or no) introduced marine organisms on the Galápagos, this would make the Islands a very special place for yet another reason. There are few biotic areas in the world with a maritime history which remains unaltered by ship-borne introductions.

Lessons from Other Regions

Patterns of invasions around the Pacific Ocean, and the results of marine introductions around the world, serve to focus concern about the potential for colonization by exotic marine species on the Galápagos.

An analysis of all the known introduced marine species that have been transported by ships, oysters, and other means, to and within the Pacific Ocean reveals that there have been major

dispersal routes, and that the Hawaiian Islands have been particularly vulnerable (Figure 5; from Carleton, 1987). Wherever ships have visited continuously over the centuries, they have acted to add species and alter the biota. Few data are available for South America (Figure 5), and no data were available for the Galápagos at the time the figure was prepared. Nevertheless, the Galápagos Islands should be no exception to these patterns of ship invasion.

Figure 5. Dispersal Routes of Marine Species in the Pacific Ocean.

On a more global scale, introduced species have had major impacts in the marine environment and scores of examples are available. These impacts may be "negative" (Figure 6), or, more rarely, "positive" (introduced plants and animals measurably increasing local primary and secondary production) and frequently "neutral" (no reported effects). It is perhaps fortunate that, to date, and given the human history of terrestrial introductions on the Galápagos Islands, no major recognized marine introductions have negatively impacted the marine region.

Figure 6. Examples of Ecological and Other Changes Resulting from the Introduction of Exotic Marine Organisms Around the World.

SPECIES	INTRODUCED FROM --> TO	ECOLOGICAL OR OTHER CONSEQUENCES
<i>Sphaeroma quoyanum</i> (isopod)	New Zealand-->California ships, 19th century	bores into intertidal sediment-->widespread coastal erosion in bays.
<i>Ficopomatus enigmaticus</i> (tubeworm)	Australia --> Japan Hawaii Europe ships, 20th century	creates massive subtidal encrusting colonies - major fouling organism blocking pipes, tide gates, etc...
<i>Codium fragile tomentosoides</i> (green algae)	Europe --> Atlantic USA ships, 1950s	colonized extensive areas (shallow, subtidal); major fouler; important influence on shellfish (oyster and scallop) industries.
<i>Styela clava</i> (sea squirt) (tunicate) (ascidian)	Europe --> Atlantic USA ships, 1970s	rapidly colonizing subtidalfouling species now dominant organism in many areas formerly occupied by mussel (<i>Mytilus edulis</i>).
<i>Eriocheir sinensis</i> (crab)	China --> Europe ships, early 1900s	burrows into and destroys river banks; blocks water channels and pipes; interferes with fishing (destroys fish in nets; damages

Future Prospects and Research

With the increasing human population and tourism on the Islands will almost inevitably come the need for increased support services -- more ships and more port facilities, docks, and wharves (Broadus and Gaines, 1987). While some mechanisms of lowering the number of vessels visiting the islands legally exist (1935 and 1937 regulations that forbid foreign merchant ships, and foreign yachts without permission, to enter Galápagos waters; J. Broadus, personal communication, 1987), an increasing number of vessels at the end of the 20th century will doubtless have an impact in the Galápagos biota: almost always associated with increased maritime activities around the world has been the introduction of new exotic marine organisms. There are clearly strong management implications here.

Numerous research needs are easily identified and have been implied throughout the above discussions. These include:

- (1) A pressing need for studies of the systematics and biogeography of Galápagos marine biota, including monographic treatments, and the encouraging and aiding of specialists to come and work on the Islands,
- (2) A thorough study of the fouling communities on ships
 - (a) at the Galápagos
 - (b) coming to the Galápagos
 - (c) in mainland harbors, such as Guayaquil.

Such studies, particularly (b), would provide a direct measure of the potential for species invasions,

- (3) A thorough study of mainland and Galápagos fouling communities, to assess what species may have been introduced already,
- (4) Coordination with other worldwide management plans focused on marine and terrestrial introductions; active interest in these problems exists in Europe, Canada, the United States, Africa, and other countries.

We do not yet have a full measure of the role of introduced marine species on the Galápagos Islands. Theoretical and empirical considerations suggest that shipping has brought species to these islands, and has left us with, if nothing else, a host of potentially cryptogenic taxa. The continued development of the Islands similarly yields certain theoretical predictions supported by global empirical evidence: increased maritime activity inevitably leads to more introductions of exotic species. The establishment of the Galápagos Marine Resources Reserve provides a foundation upon which to incorporate these considerations into a long-term management framework.

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Some Observations on Artisanal Coastal Fisheries in the Galápagos

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Several general observations on the characteristics of Galápagos fisheries must be taken into account in the formulation of a management plan:

1. Over 90% of the exploited fish species belong to one family, the Serranidae (groupers and basses) and several of the most important species among those are Galápagos endemics, or have particular disjunct island occurrences (Paralabrax albomaculatus, Mycteroperca olfax, Epinephelus mystacinus).
2. All of these species are predators, at the highest level of the trophic web, and therefore they naturally represent only a small percentage of the whole biomass.
3. The available surface water for the handline fishery within the Galápagos is probably not larger than 2700 km². The exploited species, by nature, are habitat selective for rock ledges, vertical walls, and geomorphological accidents, which again occupy only a limited percentage of the surface as mentioned.
4. Most of these species are protogynous hermaphrodites, with only the largest animals in the population being males (probably the oldest ones). The consequences of this for population dynamics under exploited conditions are unknown.
5. A calculation of catch per unit effort (CPE) in relation to effort (Shaefer model), which pools all landed fish together, suggests that the fishery might have been moving in a range just below maximum sustainable yield, and also below maximum economic yield. A growth in fishing activity due to development would not lead to considerably increased catches, but instead to a reduction in catches and revenues with respect to effort. At the same time the exploited species are important integrants of coastal systems, and unique, fishery management should at least try to keep state interference limited, and maintain the autoregulatory capacity of the fishing community. More vessels than the present ones, or vessels with increased range, autonomy or fishing capacity should be allowed only under carefully studied conditions.
6. Fisheries studies must continue to gather landing data on a very differentiated (species by species) level, registering effort and fishing intensity per unit area. This has been proven possible by using very simple logbook notes taken by operators, in cooperation with fishery authorities. More and regular emphasis must be laid in the future on sampling of landings such that population structures of individual species be followed through time and according to fished areas.

7. Major emphasis should be put on investigation of the productivity of small coastal pelagics, which are being used as bait for the handline fishery (although total catch for this purpose may not be above 20 metric tons per season). At the same time, these pelagic species are important food for protected marine species, which are the major attractions for tourism.
8. Other pelagic species such as horse mackerels (pampanos), tunas within the archipelago, and sharks, ought to be studied to determine their current exploitation. Sharks, for example, play a very important role in the insular ecosystem. Their disappearance due to heavy fishing may change the structure of the system. Their exploitation, therefore, should not be taken as simply desirable or unproblematic.
9. The fisheries authority should be advised, even before a management plan exists, that new fishing methods and gear, before being allowed, must be authorized and guaranteed as risk-free for protected species. Gill-and-trammel nets must be forbidden, as should spearguns for underwater sport fishing.
10. (Refer to 6) Studies ought to be designed to bring much finer measurements and registers of CPE (handline fishing per hour) to give more adequate measurements of fish density.
11. As much data about lobster landings between 1982 and 1986 as possible should be recovered from exporting firms. In the future, registers of landings should also include fishing effort, and areas of fishing, in order to make current practices comparable to previously existing ones (Reck, 1984). Strict data gathering methods must be carried out with the help of the authorities and the National Fisheries Institute (INP). The Subsecretary has been asked to establish an inspector's office for this purpose on Santa Cruz. Different management options must be studied, but it seems clear that freezing the fleet at current levels of operation is the absolute minimum action required. Furthermore, careful registration of all fishermen ought to be carried out. In this regard, it is important to point out that existing statistics on the actual status of the fleet do not differentiate carefully enough between the kind of fishery they are specializing upon.
12. The recruitment process for lobsters is not clear. Reproduction is year-round, whereas recruitment at the juvenile stage of settling in the benthos seems to occur in patches at very irregular periods. More thorough and systematic diving surveys in key coastal habitats might yield more information about this, which then might be correlated to remote sensing of oceanographic and current patterns. There might also be biochemical methods to trace the provenance of lobster juveniles to determine whether they are Galápagos spawned, mainland spawned, Central Pacific spawned, or recruited at the mainland coast and partially spawned in the Galápagos?
13. In general, cooperation between the National Fisheries Institute, the Oceanographic Institute of the Navy (INOCAR), the Universities and the Charles Darwin Research Station should be strengthened and developed. Examples of successful coordination of research programs do exist.

14. The exploitation of black corals for jewelry, not only in the Galápagos, but also along the mainland shore, points to the precarious situation of marine resource management and protection along the mainland coasts. The Galápagos must not only be seen as important for its uniqueness. Its marine area should also be recognized as one of the first, and maybe the most important marine reserve to be established in the whole country. The Galápagos must be considered as a unique place for training and gaining initial experience by all probable and potential governmental management agencies (Park administration, Navy, Fisheries Authorities, etc). This line of thinking might merit some further considerations.

Comments

Jimmy Jimenez, Subsecretary of Fisheries: When you speak about the industrial fishery and its possible impact, it is worth mentioning that fishing by Tuna boats within waters internal to the islands is very relevant because it has a great impact on marine mammals (Dolphin) as they are included in the incidental bycatch taken by Tuna boats.

Based on specific observations it can be said that dolphin mortality per trawl varies from 5 to 450 individuals. The impacts occur both inside and outside of Galápagos waters. It is necessary to take this into consideration in the process of formulating plans for the Marine Reserve.

Fisheries in the Galápagos Islands

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Marine Environment

The Galápagos islands are a group of oceanic islands of volcanic origin, located some 1,000 km west of the Ecuadorian coast.

There are two very different seasons in the islands: the fresh season that goes from May through October, with a permanent drizzle; and the torrid season from November through April, with abundant rains.

Wellington (1976), says that Galápagos marine biota comes from the Panamic Province, which contributes 54% of the ichthyo-fauna of the Galápagos. 23% of the Galápagos ichthyo-fauna is classified as endemic, 12% of the fauna are Indo-Pacific migrants, 8% of the fishes come from the Peruvian-Chilean Province, and 2% are considered to be similar to those of the Atlantic areas.

Fisheries

Presently, the Galápagos islands supports three fisheries activities: artisanal, semi-industrial and industrial.

Artisanal Fisheries:

These fisheries have been developing for fifty years. At first, the primary catch was the "Galápagos Cod" Mycteroperca olfax, which constituted the total landing. Another important species in the artisanal fisheries is the "lisa" (mullet) Mugil spp. Since 1973, M.olfax and Mugil spp. have represented approximately 76% of the total weight of the landings.

In the 1977-1978 season, an analysis was done on the numbers of landings. Results indicated that M.olfax contributed only 45% of the fisheries production in the islands. In the next season, 1978-1979, M.Olfax percentage decreased to 38% of the total Galápagos landings.

Between the above mentioned seasons the number of commercial species increased from 20 to 32. At the same time, between 1978-1980, new biological samples were taken aboard fishing boats of the demersal species, especially M.olfax, with the following results:

- a) 71% of the total sample were immature individuals (46,4 cm. of L.T.), in gonadal stage I, II , with ages ranging from 3 to 4 years.
- b) The reproductive stage, it was found, occurred from December through April, which also happens to be the fishing season. This confirms Coello (1986). The reproductive period is therefore coincident with an increase in temperature that occurs between the fresh and torrid seasons.

The SERRANIDAE family has benefitted the demersal artisanal Galápagos fisheries the most. So, we could observe in the 1977-1978 season, Serranidae's provision to the fisheries was in the range of 94%; and in the next season it was 84%.

The main species of the SERRANIDAE family are:

Mycteroperca olfax. Yellow grouper - Galápagos cod (Bacalao de Galápagos)

Epinephelus mystacinus. (Mero)

Ephinelus sp*. Grouper (Norteno)

Epinephelus labriformis. Flag Cabrilla

- * This is an important commercial species. Up till now it has not been possible to fully identify it, but it is almost surely an endemic species of the Galápagos Islands.

All of these species are very important for the Galápagos fisheries. In Serranidae's long life a sexual change, known as "protogenus hermaphroditism" occurs -- that is, females, after a transition stage, become males.

Another important finding in *M.olfax* is that the number of *M.olfax* males is greater than the females: 1:64; or as Coello (1986) found 1:54.

Table 1. Artisanal Fisheries Activities Between 1973 and 1986

	73-74	74-75	75-76	76-77	77-78	78-79	79-80	80-81	81-82	82-83	83-84	84-85	85-86
Total catch (net tons)	191	196	159	168	198	183	165	182	163	171	123	162	166
Numbers of boats operating													
6.5-11 m. vessels (6 - 7 persons)	17	16	12	12	16	14	14	11	12	12	11	13	16
5 - 7 m. vessels (3 persons)	3	3	4	4	5	3	7	7	7	7	6	6	7
4 - 5 m. vessels (2 persons)												8	23
Total # vessels	20	19	16	16	21	17	21	18	19	19	17	27	46

Table 1 shows the catch pattern from 1973 to 1983 with a yearly average total catch of 177 metric tons. Since 1985 it has dropped 24 percent.

The number of boats dedicated to this endeavor from 1973 to 1984 averaged 18; but, from then through 1986, it increased to 46, a 150% growth rate.

Those fisheries that have developed around the Galápagos, as well as in some shoal waters down to a maximum depth of 200 meters, Primarily use hand lines. Wellington (1984), tells us that those areas contains 99% of the marine biota of the archipelago. Therefore, wise management of these heavily-fished waters is of great importance.

Semi-industrial Fisheries - Lobster Fisheries:

The lobster de espina of the Galápagos Islands has been described only by Holthus and Loesch (1967), Barr (1968) and Reck (1983).

The commercial species are:

Panilurus penicillatus	"langosta roja"
Panulirus gracilis"	"langosta azul"

A small number of *Scyllarides astori* (langostino) are also captured as by-catch.

Initially, the catch was simple and abundant. The only gear the fishermen used were masks, a couple of swim fins and their own lungs. Most of the time, they worked in the low tide and always during the day. This method was used for several years. At the same time, alternative approaches were attempted, like "trasmallos" and "traps", with negative results.

Around 1970, air compressor-diving was introduced by the Guayaquil based fisheries. In 1972, two vessels operated with this system. The vessel MARCITA, had a three month autonomy and used seven small outboard boats (pangas) with an air compressor and three divers in each one.

Table 2. Lobster Fishery Activities Between 1973 and 1986.

	73	74	75	76	77	78	79	80	81	82	83	84	85	86
Total catch (net tons)	36.7	53.2	22.8	27.0	24.8	31.8	30.7	29.7	32.8					75
Numbers of boats operating														
6.5-11 m. vessels (6 - 7 persons)	1	1	1	1	1	1	1	1	1	1				
5 - 7 m. vessels (3 persons)										2	5	8	11	9
4 - 5 m. vessels (2 persons)					1	4	5	5	7	8	12	16	22	25
Total # vessels	1	1	1	1	2	5	6	6	8	11	18	24	33	44

Between the years 1977 and 1983, only one such ship operated in the Galápagos --SALVADOR (Table 2). Until then, information on lobster catches showed an average landing of 32 metric tons. After that time capture information is missing. In 1986, information was obtained by INGALA's (Galápagos National Institute) planning office, showing a figure of 75 metric tons for the lobster sent air cargo to Guayaquil; 17 metric tons for consumption in hotels and restaurants; and 4.6 metric tons for tourism and islander's use.

From 1977 through 1983, an average of 8 boats (of all types) operated in the islands. Between 1984 and 1986, the number of boats increased by 81%. We found, for 1986, boats that pursue two kinds of efforts: finfish and lobsters (Table 3).

Table 3. Finfish and Lobster Boat Activity for 1986.

	larger vessels	smaller vessels	TOTAL	%
San Cristobal	3	5	8	30.7
Santa Cruz	2	4	6	23.0
Isabela		11	11	42.3
Floreana		1	1	3.8
Total # vessels	5	21	26	100.0

Industrial Fisheries - Tuna Fisheries:

Two Fleets, foreign and national, extract Tuna resources from Galápagos waters. The more important tuna species are: *Thunnus albacares*, *Acanthocybium solandri*, *Katsuwonus pelamis*, *Euthynnus leineatus*, *Sarda chilensis*, *Sarda lineolata*, and *Sarda velox*.

Tuna Fishing activities developed in the archipelago around 1930. In the Eastern Pacific, the total fleet is comprised of 13 nations, that generally fish:

Thunnus albacares

Yellowfin Tuna
(Atun Aleta Amarilla)

Euthynnus lineatus

(Barrilete negro)

Thunnus obesus

Bigeye tuna
(Patudo)

(along with other tunids of lesser importance).

The Inter-American Tropical Tuna Commission (IATTC) collects data on the biomass extracted in the Galápagos. It appears that most occurrences of eggs and larvae of the tunids are found in superficial waters, with temperatures that range around 28°C. The majors areas of fishing are located in the oceanic inter currents, upwelling and divergence zones (Uda, 1936).

Fleets from about five countries presently fish in the Galápagos and adjacent areas. They use "redes de cerco" and long lines.

As for the national tuna fleet, information is provided by the logbooks for fishing vessels or given by the National Fisheries Institute (Center for Fisheries Data).

Table 4. Numbers of Fish Landings in the Galápagos Islands (metric tons).

	1981	1982	1983	1984	1985	1986
A. amarilla	1.289	1.564	1.947	1.592	2.697	.557
Barrilete	1.037	.464	.505	2.136	9.848	.559
Patudo	.034	.025	.112	0	.550	.283
Total	2.360	2.053	2.564	3.728	13.095	1.399

If we look at Table 4 we notice that there are fluctuations between the different seasons; but between 1982, 1983 and 1986, the catch is minimum, probably due to El Niño events.

Fisheries of sharks, "picudos" and dolphinfish

These fisheries developed around 1980. They use long-lines, and are operated by Korean and Japanese ships, that work in association with Ecuadorian corporations based in Guayaquil, Manta, Santa Rosa (Salinas). Also, the Manta School of Fisheries and the National Enterprise of Fisheries each operate one boat. About 8 to 10 vessels work in the area adjacent to the Galápagos Islands (ca. 15 to 20 miles off-shore) fishing for sharks, generally of the genus *Cacharinus*, the so-called white meat sharks; red meat sharks and other low quality ones.

Picudos that are fished include "gecho", merlin azul, merlin negro, pez vela and pez espada. Also fished are dolphinfish (dorado), and in smaller numbers, yellowfin tuna.

Fishing area for these species are north of Pinta, southwest of Isabela, and west of San Cristobal. Vessels visit the islands some 8 to 10 months a year and every visit lasts from 10 to 15 days.

There is some confusion regarding how much biomass is extracted from Galápagos waters, because the fisheries activities are limited to the areas or zones where the greatest quantity of those species can be found. Therefore, the vessels mainly fish the three principal sites in this section of the Eastern Pacific.

Discussion

It is obvious that artisanal fishery activities are slowly decreasing. Early on, the only species caught was the "Galápagos cod". The number of fish caught, individual weight and total length are decreasing every season. Furthermore, in every season more species are being caught.

The Black Turtles in the Galápagos Islands

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Introduction

In order to characterize coastal areas for management purposes, it is necessary to identify elements of coastal ecosystems that generate useful information. The black turtle in its various life stages; adults, males, females, sub-adults, juveniles and neonates, occur in the area of the marine reserve.

Research has been conducted mainly on the reproductive biology of the black turtle and the results were published in the Boletín Científico y Técnico del Instituto Nacional de Pesca, Vol. 6, No. 2. A local and regional overview of these turtles is presented in this report.

Local and Regional Problems

The average number of turtles, 1500, corresponds to the more abundant nesting beaches in the archipelago. However, other Galápagos beaches, visited during the nesting season, showed tracks of turtles as well.

Although the turtle populations of these latter beaches might appear to be of little significance, they are important in terms of their potential to increase yearly production of neonates, despite the unfaithfulness that turtles have toward "their" nesting beaches.

The protection of the nesting beaches of the black turtles of the Galápagos is related to the measures taken for all the archipelago starting in 1936, the year in which the Galápagos National Park was created. It has been supported through the years by the national legislature. But it is necessary to mention that the black turtle in the area of the Galápagos, was found to be under threat of commercial exploitation in the years 1971 and 1972, when the vessel "Chicuzen Marou" sacrificed, after Green (1978) and Cifuentes (1975), between 1,000 and 10,000 young, subadults, and adults, males and females turtles. On the other hand, part of the migratory population of the Galápagos could have been sacrificed on the continental coast of Ecuador, during the now barred commercial exploitation of marine turtles (Hurtado, 1981, 1982).

At present, most of the nesting beaches of the black turtle are protected under the legislation of the National Park, whose jurisdiction covers some 96% of the total area of the archipelago. Exempt from this protection are: beaches to the North of Santa Cruz utilized in sand mining; the beaches of the colonized areas, such as Puerto Villamil, under municipal jurisdiction; and

the beaches of the island of Baltra, in which a military base is located. Under these conditions, around 50% of the reproductive stock, corresponding to Quinta Playa and Bahia Barahona, are presently protected in one area of the National Park. These beaches are considered as the sole reproductive unit belonging to Isabela island, because 15% of the turtles of these beaches, emerged or interchanged in Quinta Playa and Bahia Barahona beaches during the reproductive season.

At these two beaches, turtle predators have been reported -- the beetle Trox suberosus, considered by Allgoewer (1980) to be indigenous, and foreign wild pigs, Sus scrofa (Green et al., 1981). The separate or joint activity of these predators have greater effect in Quinta Playa than in Bahia Barahona. Notwithstanding this depredation, Quinta Playa and Bahia Barahona still produce 51% of the neonates that emerge to the surface and go to the sea.

Accordingly, future problems of these beaches will be the increase of tourism and excessive urban growth in the neighboring port of Villamil.

Until 1979, visitors to Quinta Playa and Barahona were exclusively scientists. In succeeding years, beyond the scarce tourism controlled by the Galápagos National Park, visitors infiltrated by sea. It is worthy to point out that visits to the nesting beaches are not necessarily detrimental to the protection of the turtles. Such visits could be educational, provided that the National Park has the means to increase control, since problems like furtive collection of eggs and sacrifice of egg-laden females could increase in Puerto Villamil where turtles migrate from neighboring nesting areas.

South of Baltra Island (Las Salinas) and north of Santa Cruz (Las Bachas), a total of 31.6% of the nesting turtles and 38.1% of the yearly neonates population was recorded. Both beaches showed the highest number of births and emergence of neonates, reaching 69.9% in Las Salinas, and 78.4% in Las Bachas (Green, Ortiz, 1981). Both sites were treated as reproductive units, due to the migratory movement and interchange of the turtles between both beaches. Apparently, only natural depredation exists at these beaches. Although wildcats, which maraud turtle nests and probably capture emerging neonates, have been detected, this activity has not been proven or quantified. Thus, the primary danger to these nesting areas is due to sand-mining activities north of Santa Cruz where the sand is extracted. Workers have reported the existence of ear-marked turtles, originating from Las Bachas and Las Alinas. Sand-mining destroys many nests, resulting in the loss of nesting beaches for turtles unfaithful to their other nesting beaches.

A continuing problem is exploitation of egg-laying females of Las Salinas (Baltra Island), by the military elements, who are known to have collected neonates as souvenirs.

In the beach Espumilla (Santiago island), 9% of the reproductive stock emerge, contributing only 0.3% of the yearly production of neonates. The problem in this nesting beach is the wild pigs, who can destroy turtle nests, despite the many methods of protection attempted by the National Park.

Although Espumilla beach presents a low percentage of nesting turtles, its importance comes from the fact that turtles originating in other nesting beaches often migrate there. This pattern of behavior was present in around 10% of the recruiters and 12% of the migrants on every beach studied.

Picona and Bartolome beaches were monitored during a single nesting season. Monitoring in Bartolome Island was done in 1979, and coincided with one of the lowest records of observed turtles in the Galápagos archipelago. Monitoring in Picona in 1982 coincided with the highest record of turtles in the Islands. The total sums of both records constitutes around 10% of the reproductive stock, and a similar percentage in the yearly production of neonates.

Only on these beaches has the presence of the predator Trox suberosus been observed in the turtle nests. The effects of its presence are greater in Picona than in Bartolome.

In the nesting beaches where tourism does occur, like Bartolome and Espumilla, it has been observed that electric light coming from the large anchored boats, produces disturbances in the behavior of the turtles. The reduction in the number of turtles that come up to the beach on nights when electric lights are in operation has been considered as proof of the behavioral change.

25% of the reproductive turtles of the Galápagos are found on the tourist beaches. It has been suggested to authorities to implement more restrictive measures to prevent further decreases in the turtle population in this region of the East Pacific.

As was previously mentioned, the nesting colony of *Chelonia mydas* is one of the more abundant in the East Pacific. Part of the nesting population in the Galápagos migrated to continental waters of several countries from Costa Rica to Peru. Reports of recoveries of marked turtles originating in the Galápagos, were made in the greatest number of cases by active fishermen of marine turtles, who provide turtles as protein to some coastal inhabitants of Panama, Colombia, Ecuador and Peru. Inhabitants of the Pacific coast of Costa Rica do not consume turtle meat.

Protection of turtles in those countries where the Galápagos turtle have been found is limited to a few legislative references, generally isolated and not coordinated with other countries of the region. Those legislative efforts deal with protection of wildlife in general. In the case of marine turtles, the legislation is not enforced or compliance to it is avoided. Thus, for example, while Ecuador enforces its national laws by prohibiting the exportation of turtle skin or other by-products, it looks like the South of Colombia has increased clandestine commerce (Hurtado, 1981). Such commerce probably escapes the control of the countries bound by the International Convention on Wildlife and Flora Commerce.

Unfortunately, the nature of illegal commerce, the fear or the "collaboration" of fishermen to provide information on the capture of turtles, the lack of information on figures of capture per species, both accidental and for subsistence, does not allow us to know the level of mortality caused by fishing of the Galápagos black turtle in the area where it is distributed.

Greater knowledge of the biological cycle of the turtles is being used to protect the population of nesting black turtle in the East Pacific. Restricting fishing of the wild population to subsistence level for the human populations that inhabit the distribution areas will help.

Marine Resource Extraction: Black Coral

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Black Coral, Antipathes panamensis, is harvested both in the Galápagos Islands and from coastal waters of mainland Ecuador. With increased tourism, the demand for this resource has increased as coral is used in the fabrication of jewelry and other sculptural items. How much raw material is derived from continental sources compared to island sources is not known.

State of Knowledge

General biology and exploitation of black corals in the Galápagos is described in Martinez and Robinson (1983). Two species are present in the Islands, Antipathes panamensis and A. galapagensis. The latter species is endemic but not presently utilized. Black corals are distributed throughout the archipelago, favoring vertical rocky substrates, underhangs and caves. The depth of their habitat ranges 3 to 50 meters with densities (where they occur) ranging from 0.1 to 0.5 colonies/m². Growth rates appear to be slower than other species, i.e. less than 6 cm/year typical of Hawaiian corals (Grigg, 1977).

Colonies of black corals possess separate sexes, sexually reproducing by broadcast spawning. The length of the planktonic stage is not known. Asexual reproduction is possible by fragmentation and wedging of broken branches in rock crevices.

Management Problems

Anecdotal accounts of overexploitation (Kastelwijn, 1987) and rapid expansion of black coral products offered for sale in the Islands (Villa, 1987) are reported. Shallow depth distribution, apparent slow growth rates, a time consuming mode of reproduction and high demand for this resource, present the conditions for overexploitation of Antipathes panamensis in the Galápagos. The lesson learned from other tropical regions, where harvesting of black coral reduced populations to low levels, indicated that imposition of strict harvesting guidelines and limited entry to the fishery were necessary. A similar situation may already exist in the Galápagos Marine Reserve.

Future Directions and Recommendations

Continued studies of black coral distribution and population densities need to be conducted and compared to earlier information gathered in 1982 and 1983. Studies of reproductive biology and growth rates are incomplete. The amount of commercialization, and amounts harvested in the Islands needs to be quantified. Conservation measures need to be addressed as soon as possible. Martinez and Robinson (1983) suggested several possible conservation measures without specifying which of the alternatives might be appropriate for the Galápagos (Table 1).

Table 1. Galápagos Black Coral (*Antipathes panamensis*):
possible conservation measures (not mutually exclusive).*

1. Prohibit harvesting through considerations of CITIES (Committee on International Trade in Endangered Species) appendix II listing and Ecuadorian forestry law.
2. Protect the resource through zoning schemes under the Galápagos Marine Reserve or Marine Park framework.
3. Limit entry to fishery.
4. Report all catch data to local fisheries inspectors.
5. Apply minimum size limits to black coral colonies. (Ex. trunk diameter > 1.5 cm).
6. Require that a residual portion of colony be left for regeneration, e.g., employment of saw to cut harvested branch 10 cm from base.
7. Apply "reforestation" or "replanting" methods to encourage asexual propagation of colonies.
8. Promote development of artisanal crafts employing alternative materials, for example: Ceramics, glass; wood carvings derived from introduced tree species.
9. Marine education: life history information, fisheries information, fishery methods.

* Extracted from Martinez and Robinson (1983)

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Marine Minerals: Misconceptions and Mythologies

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Marine mineral deposits, such as the marine polymetallic sulfide (MPS) deposits that form around undersea hydrothermal vents, ought not to be a consideration in planning and implementing the new Galápagos Marine Resources Reserve. No such deposits have been found within the Reserve, and those found elsewhere are not properly considered resources. Their near-term (1-15 years) prospects are nonexistent and their longer-term (15-75 years) prospects are little better, speculative at best.

However, the name "Galápagos" has been associated with MPS deposits, found hundreds of miles east of the Reserve (at about 0 degrees 45'N and 85 degrees 5'W at 2500-2900 m depth). These "Galápagos" deposits may have influenced some policy makers during the process of establishing the Reserve. So it is well to address the issue during the Reserve's planning phase.

MPS Deposits

The MPS deposits are created by hydrothermal processes associated with oceanic tectonism, where heated seawater percolating through rock fissures leaches metals from the rock. When this metal-laden solution rises back into the cold ocean, the metals precipitate out as sulfide mineral deposits containing such metals as zinc and copper (see Table 1). These deposits build up into chimney formations 1-5 meters tall around the vents, called "smokers."

Table 1. Metal Concentrations from Selected Marine Polymetallic Sulfide Sites.

<u>Area</u>	<u>Zn %</u>	<u>S %</u>	<u>Fe %</u>	<u>Cu%</u>	<u>Pb %</u>	<u>AG (ppm)</u>	<u>Cd (ppm)</u>
Juan de Fuca (1)	0.63-54.0	n.a.	1.8-50.5	0.0003-0.32	0.06-0.25	3 -290	0-490
Guaymas Basin (2)	30	n.a.	n.a.	1.0	0.10	300	n.a.
21°N EPR (1)	0.12-41.8	0.74-39.7	0.61-26.2	0.13 -1.3	0.04-0.61	1.6-241	20-890
13°N EPR	No compatible data is as yet available						
Galapagos Rift (1)	0.14	52.2	44.1	4.98	0.07	10	31

(1) Source: Bischoff et al., 1983

(2) Apparent average concentrations based on limited existing samples
Source: Cruickshank, 1982

Misleading Reports

It is not surprising that some policy makers in Ecuador have inflated views of the economic significance of MPS. Early press reports, attracted by the exciting scientific discoveries, highlighted the deposits' alleged economic "value" (see Figure 1). Several reports in the technical literature also suggested that MPS are valuable resources (Bischoff et al, 1983; Cruickshank, 1982; Malahoff, 1982a) or "ores" (Mottl, 1981). These were misleading and based on faulty economic understanding.

Come and get it — \$2b ore in Pacific

United Press International

WASHINGTON — A \$2 billion-plus deposit of copper and other strategic metals there for the taking has been found on the Pacific Ocean floor west of Ecuador, and similar lodes probably exist off Oregon and Washington, the government announced yesterday.

Dr. Alex Malahoff, chief scientist of the National Ocean Survey, said the discovery and the possibility of others near sea-bottom cracks around the world could mark a "dramatic turnaround" in the global assessment of accessible mineral deposits.

The Russian-born geologist held a fist-sized chunk recovered by robot arms on the research submarine Alvin 8250 feet deep and said he believes it represents the richest known ore left anywhere in the world.

Malahoff said the deposit, marked by a forest of stalagmite-looking cones tens of feet high, was at least 130 feet thick, 650 feet wide and 3200 feet long. It was located along a fracture zone in an undersea ridge 240 miles east of the Galapagos Islands and 350 miles west of Ecuador.

Underwater photographs taken over a similar geological structure known as the Juan de Fuca rift 180 miles west of Washington showed what ap-

peared to be similar deposits. Another promising area is called the Gorda rift, 70 miles off Oregon's coast.

Conservative assays of samples returned by the Alvin, including one chunk weighing 240 pounds, show the deposit is 10 percent copper and 10 percent iron and contains lesser amounts of silver, zinc, cadmium, molybdenum, lead, tin, vanadium and cobalt. Malahoff said French scientists also believe gold may be locked in some of the minerals.

He said the deposit lies exposed on the sea floor and could be recovered by technology available today. He said the ore body is in international waters and is not now covered by international law, making it available to anyone.

The deposit is so new, however, that the fledgling ocean mining industry has not yet explored the possibility of tapping it. Malahoff said French and German scientists also have shown an interest in such deposits.

Malahoff and other scientists from the National Oceanic and Atmospheric Administration and from the academic community completed mapping the deposit last month from the Alvin — the only submarine in the world capable of picking up mineral deposits from the deep-sea floor.

Figure 1. Misleading early press reports (as in this example from October, 1981) may have created false expectations. MPS deposits contain no "ores", which are defined as "the naturally occurring material from which a mineral or minerals of economic value can be extracted at a reasonable profit" (Bates & Jackson, eds., Dictionary of Geological Terms, Doubleday).

Abundant Competing Resources

Although the MPS deposits are composed largely of useful substances such as iron, sulfur, copper, zinc, lead, silver, and cadmium this does not automatically establish them as a valuable resource. Some metals do appear to occur in them at concentrations greater than in many producing mines, but as long as demand can be satisfied more economically from other sources the metals in MPS will remain unexploited. Iron and sulfur, for example, are both economically important commodities that appear to comprise a major portion of MPS mass. Because of the overwhelming abundance of known cheap sources, however, neither of these elements is ever seriously proposed as a commercial product from MPS recovery. The same kinds of factors limiting the attractiveness of iron and sulfur in MPS also affect the other contained minerals in varying degrees.

At prevailing rates of consumption, current onshore resources of these metals would not be consumed for many years. If we assume broadly that identified onshore resources for each commodity are of higher quality and will be used before any potential seabed sources, this "resource life index" may suggest a waiting time before exploitation of seabed materials could begin. At current consumption rates, the world's onshore copper resources would not be consumed for 205 years. Those of zinc and lead would last for 274 years and 418 years respectively. Such "life indices" are naive in not accounting for increasing consumption with population and economic growth. But neither do they include the influence of additions to resources over time from previously undiscovered or uneconomic conventional deposits onshore.

Projected percentage depletion of world resources, based on United Nations low-case assumptions about growth in developing economies, have been reported by Leontief et al. (1982) using a sophisticated input-output model of the world economy. By the year 2030, Leontief et al. project only 86% depletion of current onshore copper resources, and only 47% depletion for zinc and lead. These depletion rates, furthermore, tell little about the rate at which new resources will be added or the cost of doing so. In addition, the input-output technique is not well suited to capture the effects of recycling, conservation, and substitution over time. Good economic substitutes exist for all of these materials in most of their uses, and other substitutes emerge as economic alternatives when a material becomes scarcer and relatively more expensive. Great reductions in copper consumption could be achieved readily by substituting aluminum or non-metallic conductors called synmetals. Progress is also being made on copper-saving end-use innovations. Lead and zinc also face serious long-run demand reductions for their current uses.

Reserves of copper, lead, and zinc increased by factors of 4.6, 3.6, and 2.7, respectively, between 1948 and 1976. Over the same period, production and consumption of these commodities were increasing by factors of 3.4, 2.4, and 3.2, respectively. New reserves were thus being added at a greater rate than the increase in consumption for both copper and lead and at nearly the same rate for zinc. Much of this increase came from newly discovered deposits, and resources have been increased apace.

No Scarcity Indicated by Price Trends

In the absence of a more precise measure of increasing scarcity of natural resources, the long-term behavior of market price is probably as good a signal as any. If the relative scarcity of a material is increasing, we would expect its real price to rise. Trends in real price indices for a representative composite of zinc (32.3%) and copper (0.81%) in MPS deposits are thus examined here by using both linear and quadratic fits (Figure 2). From this limited evidence we cannot conclude that price behavior is signaling increased relative scarcity of these materials.

Figure 2. The behavior from 1958 to 1983 of real price index (1967 = 100) for grade-weighted composite prices or principal metals contained in typical Marine Polymetallic Sulfied (MPS) deposit (32.2% zinc and 0.81% copper, based on Bischoff et al., 1983), and showing linear and quadratic fits.

Prohibitive Costs and Absent Technology

Costs are a critical controlling factor. Mining sulfide deposits would be prohibitively expensive in the short run and would require the development of an entirely new technology. A U.S. Interior Department panel on marine hard minerals engineering technology assessment concluded: "Little or no technology exists for mining mineral deposits in waters of 100 to 10,000 feet, ... and adaptability of existing systems, or parts thereof . . . is essentially unknown." Commercial exploitation would require new methods to assess the grade and tonnage of prospective deposits, new systems to recover solid material from on and beneath the seabed, and modification of metallurgical processes to extract the metals from the ores.

High Scientific Value

It is important to distinguish between the value of knowledge about MPS deposits and the resource value of the deposits themselves. Though the latter may be negligible, knowledge about MPS appears to be of great value. Information on the genesis of mineral deposits and their settings can be critical to the success of onshore exploration methods based on geologic inference. Close study of MPS mineralizations should also foster improved inferences about such basic mysteries as geotectonic processes and the globe's thermal and geochemical dynamics. Biological research on the unusual and fascinating communities of organisms around the vents is only beginning and could lead to major advances in scientific understanding of life processes (Grassle, 1986).

Conclusion

No MPS deposits have been found within the Galápagos Marine Reserve. If they are found, they (like other MPS deposits) will be of little or no economic interest. Abundant competing resources onshore, the absence of necessary technology, and prohibitive costs virtually preclude the competitiveness of MPS deposits. More detail on these conclusions is reported in Broadus and Bowen (1984) and Broadus (1987). The MPS deposits are, however, of great scientific interest.

Proposal

If potential MPS deposits are included in the Reserve management plan, it should be not as potential economic resources but as *Special Scientific Reserves*. The Reserve may wish to promote research on these phenomena. Their biological communities offer many of the kinds of scientific opportunities in biogeography, evolution and genetic reserves that are the hallmark of the Galápagos Archipelago.

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Impact of Marine Resource Exploitation on Biological Ecosystems

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Among the marine mineral deposits we can consider two large groups:

The first category of marine minerals are those from the continental shelf, such as placers, sand, shell accumulation, etc. The second group is comprised of minerals from the deep ocean basins that could be mined in the future, such as polymetallic nodules, hydrothermal and phosphate deposits, metaliferas mud, etc.

The diminishing abundance of the second group of minerals on the sea floor has called the attention to the world. Different investigators have calculated the profit from those deposits. Some opinions are:

"...the ferromanganese nodules on the sea floor can be a source of Cobalt, Copper, or Nickel, and able to satisfy the actual use of those metals during the next hundred millenium. Goldberg, E.D., 1976).

"...In the manganese nodules found on the first meter of sediments in the Pacific Ocean there are 50,000 times more nickel and 100,000 times more cobalt from the actual annual production" (Menard, W., 1964).

"...the metaliferas mud found in the Red Sea into the 10 first meters of sediment present concentrations of Co 1, 3%, Zinc 3, 4%, Ag 0.0054%, Pb 0.1% and Fe 29%" (Cronan, D.S., 1980)

On the subject of metallic polysulphurs, recent investigations in the Galápagos Rift indicate places where concentration of Cu, Zu, S, Ag are 8.54%, 7.73%, 3.7%, and 0.54% respectively.

Despite the fact that most of these resources are now hard to get, interest in mining them continues, as Kenneth Emory from Woods Hole Oceanographic Institution (WHOI) says: "It is possible that the manganese nodules, with their associated extraction problems, represent today an out of hand resource from the economic point of view, but perhaps in the future they will become a profitable resource. . . ."

Methods and techniques, such as platforms, giant dredges, and big vacuums, have been developed to extract these minerals. More importance has been placed on developing the devices

than on studying the impact mining them could have on other issues. ALVIN's¹ investigations indicated that a rich and varied fauna, truly an "oasis", is found near the sources of hydrothermal activity, producers of metallic polysulphures (McDonald, K.C., 1980). During the COPANO campaign in 1979, Guy Pautout and Michael Hoffert observed that ". . .the role of organic productivity followed by dissolution and diagenesis is the dominant phenomenon for the enrichment of the nodules in transitional metals. . .". Finally, in order to demonstrate the close relationship between biological activity and mineral resources, we can quote V. Marching and H. Gundlach. They say that 90% of the sediment samples taken from the Galápagos Rift area (De Steiguer Reef) are composed of organic material, foraminifers, coccoliths, echinoderm spines, etc.

The first impact of mineral mining would be the destruction of benthic life around the accumulation areas. Their recovery is impossible to predict.

A second problem created by mining is resuspension of sediments. Sedimentation rates in the East Pacific start at 1mm/1000 years in most cases (Marching, V., 1981). It is estimated that perturbation could cause variation of vertical distribution of masses of water, light absorption, temperature, dissolution, etc.

Finally, the contamination of surface water should be addressed. If we consider what the Albatross encyclopedia says about submarine mining: "the remains of mineral mining can be easily eliminated by throwing them back to the sea," we can expect that sediments and chemical products will be around at the surface for awhile.

NOAA makes these recommendations for determining the environmental impact of marine mineral mining:

1. Evaluate the environmental conditions of the potentially interesting areas.
2. Establish the changes produced by mining on the benthonic and pelagic life.
3. Take measures to minimize harmful effects, and
4. Monitor changes in the environment during mining to detect the impact, measure its magnitude, and mitigate damage.

The problem is this: we need those minerals, but we need to find an equilibrium. We want the minerals for the development of the human race, but we must preserve the ecosystem for survival of the race.

¹Manned submersible operated by WHOI

Tourism in the Galápagos

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Visitor use of the Galápagos marine area has been analyzed since marine areas are the major attraction for visitors to the Galápagos National Park.

In order to arrive at the tourist areas, maritime transportation is required. Analysis of the impact of tourism on these areas therefore includes the use of the marine surface for transportation, visits to the coastal zones, and visits to several underwater spots near land-based attractions.

The data does not discriminate between the visits to land and sea locations. For that reason analysis of the number of visitors is made globally.

Massive visits to the Galápagos National Park started around 1968 and, since then, have been gradually increasing (Cifuentes, 1981), from 7,500 tourists registered in 1974 to 17,445 visitors in 1980 and 26,023 in 1986, which actually exceeds authorized ceilings.

The Master Plan for the Use and Development of the Galápagos National Park recommends allowing no more than 12,000 visitors per year. The Forestry District of the Galápagos, however, does not count the human and material resources that are necessary for enforcement of the Plan's recommendations. Unfortunately, the Plan does not have provisions for actually preventing the number of tourists from exceeding the ceiling: financing for the management plan never reached 50% of the plan's projected expenditures until 1980.

The report of the High Level Commission (1981) acknowledges the need for the Galápagos Forestry District to have sufficient financial resources to manage this number of people, but it does not describe measures that provide the Galápagos District with appropriate income to support one of the goals of the Park, i.e., not to exceed the ceiling.

Figure 1 shows how in two cases the limit was surpassed, while at the same time, the management means were reduced. Analyzing the figures on tourism (Figure 1), a strong imbalance between Ecuadorian and foreign visitors can be noticed. The number of foreigners increases until 1980, then it plunges and stabilizes up to 1985, with a slight increase in 1986. Meanwhile, the number of Ecuadorian tourists grew rapidly, peaking in 1984. It seems that the 1982-1983 El Niño did not affect tourism.

To examine the trends in tourism during the year, we have averaged the data for the 1979-1986, obtaining the curves shown in Figure 2. Even if we make our analysis on a yearly basis there are anomalies, especially in the last year (Figure 3).

Figure 1. Plot of Numbers of Visitors Per Year to the Galápagos National Park between 1974 and 1986.

Figure 2. Plot of the Numbers of Visitors Per Month to the Galápagos National Park Between 1979 and 1986.

Figure 3. Plot of the Numbers of Visitors Per Month in 1986 to the Galápagos National Park.

The level of Ecuadorian visitors goes up in April (Coast region holidays), August, and September (holidays in the highlands -- the Sierra); the numbers go down in June, July, November and December. The number of foreign visitors is highest in January, March, July, August and November (Figure 2); and lowest in May, June and September (higher in boats).

If we make monthly averages for the total number of visitors, we can observe that the more crowded months are February, June, October, and November. In December the numbers drop, because in order to proceed with the closure of the data for the year's end, not all the reports of travel arrive in a timely manner.

Since July 1986, there has been an automatic system to record tourist visits, that allows analysis of the numbers, taking into account sites and country of origin. The more popular locations from July through December 1986 are: Plazas Sur, Bartolome, and Seymour.

Comparing the analysis of Garces and Ortiz (1982) and Moor (1981) we see that the relationship is maintained. In Figure 5, the distribution of the more visited sites is shown as well as those with the least visitors.

Figure 4. Monthly Flow of Visitors to the Galápagos National Park in 1986.

Galapagos National Park Service

Flow of Visitors in 1986

The origin of most of the visitors to the Galápagos National Park in the period 1979-1981 (after Moore et al. and Garces et al.) are: Ecuador, United States, Germany and France. The only official visitor's site for the marine area is the Corona del Diablo; however, visits to submarine sites near land attractions are being offered by tourism operators of their own initiative, as are visits to more distant attractions, like Pinzon and the Beagle islets.

In recent years, tourism to the Galápagos has been cause for concern and dissent at many levels, creating a clash of interests between the investors, on the one hand, and those concerned with efficient public management of tourism levels, on the other.

The constitution of the patent and limitation of marine transportation to the visitors' sites have been the only mechanisms for curtailing arrivals of visitors. Some damage is already evident, for example, destruction of the path in Bartolom, garbage in Plaza Sur and Santa Fe, and the strange behavior of the birds in Seymour Norte. There are also indirect effects: development of infrastructure, services, immigration; potential impacts that are liable to affect the natural resources; urban growth; and profit-oriented resources extraction.

Environmental education alone will not solve these problems. Political decisiveness, strength of regional solidarity, and definition of objectives could support our goal of conservation of resources.

Figure 5. Popular tourist sites in the Galápagos Islands.

Figure 6. Popular tourist sites ranked by three levels of popularity.

Galápagos Tourism: The Importance of Industry Structure

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One rationale for a marine reserve is to offer alternative tourist attractions and spread visitor traffic. More generally, elaboration of a marine reserve may be seen as a way to attract more tourists and increase the flow of foreign earnings into Ecuador.

Examination of certain basic economic principles makes it clear that in this context, development of an open-entry, competitive tourism industry, as is happening in the Galápagos, may actually lead to reduced economic returns for Ecuador, a transfer of economic surplus from Ecuador to foreign tourists, and an increase in environmental degradation, and eventually to a possible reduction in tourism demand.

Put otherwise, a controlled-entry market with only a few regulated firms (perhaps assisted by governmental limits on supply) is more likely, if demand is relatively price inelastic, to generate larger tourism revenues and greater profits, with fewer tourists (Tisdell, 1984). Such a concentrated, controlled industry is also more likely to be responsive to governmental policy goals. Further, when environmental external costs are present, the controlled industry will, in seeking its own profits, come closer to optimal output levels than a free entry, competitive industry. Observation of the growth of tourism, the proliferation of tourism suppliers, and the growing diversity of options available to tourists, however, suggest that the industry structure is moving dramatically toward the open-entry competitive case in the Galápagos.

Maximizing Tourist Revenues through Rational Control

Figure 1 illustrates the point. Assuming an inelastic linear demand curve (showing the number of visitor-days tourists will buy at each price) and a constant marginal cost of supply (MC), an open-entry competitive market will reach equilibrium where price = $P_c = M_c$ and demands, thus = V_c . At any price above this, ($P > M_c$) profits would attract new entry, offering lower prices, until price is competed down to $P_c = M_c$ and profits = 0.

Figure 1. Comparison of limited-entry, regulated industry structure and open-entry, competitive industry structure in terms of effect on price, revenue, profit, number of tourist visits, and environmental costs.

With a concentrated, controlled entry industry, the situation is quite different. A regulated "cartel" for example will maximize profit by setting price at p^* , where marginal cost just equals marginal revenue. At this higher price, tourists purchase only V^* visitor days ($< V_c$). Revenues in this case are indicated by the rectangle $P^* A V^* O$. They are larger than in the competitive case (rectangle $P_c B V_c O$) even though fewer tourists arrive. Also, profits, measured by the rectangle between $P^* A$ and P_c , are earned.

If, in addition to the marginal cost incurred by the industry, there are external environmental costs (EMC) imposed on the nation by tourist visits, then the deviation from the optimal solutions in the competitive market ($V_c - V^*$ and $P_c - P^*$) are greater than in the restricted market ($V^* - V^*$ and $P^* - P^*$).

These results depend critically on the price-inelasticity of demand, where the reduction in quantity purchased is less than proportional to a given increase in price. Preliminary indications from a pilot survey of tourists in the Galápagos by Marine Policy Center Economist Steve Edwards (the Marine Policy Center is a part of the Woods Hole Oceanographic Institution) indicate that demand there probably is price-inelastic.

A challenge for scientific research is to determine the relationship between tourist visits and environmental effects in the marine environment that might be associated with external costs (EMC). This would help in the rational regulation of the supply of tourism services.

With this background four related issues warrant comment: (1) investment in conventional tourist attractions, (2) recommendation effect, (3) congestion effect, and (4) distribution of visits across sites.

Investments in Conventional Attractions:

Some proposals have been made to expand Galápagos tourism by developing other, more conventional, attractions such as marinas, casinos and beaches. Many facilities are available elsewhere to meet such demands, and the presence of such facilities in the Galápagos could "spoil" the market for "nature lovers" and reduce their inelastic demand. Short-run private gains could be made at the expense of longer-run public rents earned through the National Park (Tisdell, Broadus and Edwards, 1987).

Recommendation Effect:

Through a "recommendation effect", former visitors may lead friends and acquaintances to come to the Galápagos. They may be more likely to do this if their consumer surplus (area between the demand curve and the price level in Figure 1) is large. Therefore, it may be optimal to charge a price below the near-term profit-maximizing price (p^*) to maintain the recommendation effect over time.

Congestion Effect:

Congestion may effect demand and so must be considered in determining optimal price (Fisher and Krutilla, 1972; McConnel and Sutinen, 1984). Where congestion effects are present they lower demand. This reduces the number of visitor days that will maximize revenues and profits.

Further preliminary results from the 1986 tourist survey indicate that some congestion effect may be appearing in the Galápagos (Tisdell, Broadus and Edwards, 1987). The survey was conducted during January-March, 1986, when nearly 5,800 tourists visited Galápagos. Over 350 useable responses were returned. About 2.3% of the respondents thought their group was "far too big" and 16.7% thought their group was a "little too big". Tourists were more bothered by seeing other groups.

Up to 5 other groups were seen by 9.3% of the tourists. Among these tourists, 9% found the encounters "very bothersome" and 28% "somewhat bothersome". Congestion effects raise at least two policy issues, whether to curtail the flow of tourists or to spread visits more across sites.

Distribution of Visits Across Sites:

If the object is to minimize the environmental loss from a certain total number of visits to all sites, and if there are falling marginal environmental losses from visits (each additional visitor to a site imposes less extra damage than earlier visitors), then it may be best to concentrate visits.

Conclusion

Over time, an open-entry competitive tourism industry structure can be expected to push prices toward marginal cost, to reduce profits, and to reduce total revenue if demand is price-inelastic. Preliminary evidence from the Galápagos indicates that tourism demand is price-inelastic, which suggests that limited-entry, concentrated or controlled industry structure may be financially superior. This raises issues of the distribution of gains, but otherwise foreign tourists are benefitting at Ecuador's expense.

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Satellite Observations of El Niño

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Perhaps the most graphic examples of how remote sensing can be applied to large scale oceanographic problems, such as the effects of El Niño in the Equatorial Pacific, have been provided with the AVHRR (Advanced Very High Resolution Radiometer), carried aboard the polar orbiting meteorological satellite. The thermal band of the AVHRR permits the mapping of sea surface temperature (SST) over the entire globe, on a daily schedule, with a surface resolution of approximately 1 km. Figure 1 illustrates work published by Richard Legeckis of the National Oceanic and Space Administration in which AVHRR-derived sea surface temperature of the equatorial pacific was used to investigate the extent of the 1982-83 El Niño event.

Figure 1. The Effect of the 1982-83 El Niño Event upon Equatorial Pacific SST. Cross-hatched areas indicate SST of 2 to 6°C higher in January, 1983 than in January, 1984. Data was collected by the NOAA polar-orbiting meteorological satellite NOAA-7 using the AVHRR Scanner and was analyzed by Richard Legeckis at the NOAA Satellite Data Information Service.

Two dates are represented - 20 January 1984 (a normal year) and 20 January 1983 (an El Niño year). Differences in sea surface temperature were computed between the two dates and hatched areas indicate regions where the sea surface temperature increased during El Niño. As the normally constant westerly equatorial trade winds decreased dramatically during El Niño, decreased surface stress permits a slowing and eventual reversal of the South Equatorial Current. This results in a warming of equatorial surface waters in the Eastern Pacific, waters which include the Galápagos Archipelago. Such changes in sea surface temperature are detected by the AVHRR. AVHRR imagery, therefore, represents a valuable data source in oceanographic circulation studies and should be given a high priority in the Galápagos Marine Resources Reserve (GMRR) Management Plan.

El Niño, especially the 1982-83 event, is known to produce dramatic, unanticipated, and for the most part, adverse effects upon the ecosystem and economy of the Galápagos Archipelago. Because El Niño events are episodic in nature, and therefore difficult to anticipate precisely, they perhaps constitute the greatest potential risk to any Galápagos management plan. This potential risk should be expected to increase with that of human activities (tourism traffic, development of population centers, and waste disposal). The study of El Niño as it relates to the Galápagos region should include information on:

- general eastern equatorial circulation,
- inter-island circulation,
- phytoplankton distribution,
- seasonal and annual primary productivity,
- secondary productivity, and
- endemic species vitality

A study addressing each of these points should be given a high priority within the GMRR Management Plan.

Remote sensing can and should play a major role in investigation of El Niño as it relates to the Galápagos Archipelago. In the absence of an ocean color imagery, (CZCS data), which has been shown valuable in estimating phytoplankton pigment distributions, imagery capable of mapping sea surface temperature with reasonable high spatial resolution should be periodically analyzed. The NOAA AVHRR seems optimal for this purpose.

There are several reasons why periodic analysis of AVHRR imagery should be considered as a component within the GMRR management plan:

- the data is inexpensive,
- the data is easily obtained,
- temporal and spatial coverage is high, and
- Ecuador (CLIRSEN) presently has the capability to computer process AVHRR imagery.

Many of the remote sensing requirements identified in this section are identical to those expressed in the section pertaining to phytoplankton productivity. The ultimate data requirements are similar; monthly, seasonal and annual variations in phytoplankton distributions. Therefore, all comments pertaining to possible alternatives to the now defunct CZCS are directly applicable here. Radio tracking of seabirds as they feed and, if possible, phytoplankton distributions derived from TM imagery both represent potentially valuable data bases if collected coincident with any future El Niño events.

The Warm Season of 1987 Off The Coast of Ecuador and Its Influence on the Galápagos Islands

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The phenomenon of El Niño is the most spectacular example of interannual variability in the ocean with important repercussions on the climate and the marine ecosystem. The El Niño event of 1982-83 has probably been the most spectacular occurrence of this century and the most documented. Interest in the El Niño phenomenon intensified with the realization that this event is one of the global anomalies affecting oceanic and atmospheric conditions. Atmospheric changes were identified many years ago in relation to southern oscillation, but their relationship to the El Niño phenomenon was established only during the last 15 or 20 years. Actually the El Niño/Southern Oscillation (ENSO) interaction comprises a cycle between the ocean and the atmosphere in which changes in wind conditions also cause changes in superficial water temperatures and affect atmospheric circulation.

The No. 55 group of SCOR (Scientific Committee for Oceanographic Research) has defined El Niño as an affluence of warm waters towards the coasts of Ecuador and Peru, which can advance as far as 12°S and possesses positive temperature anomalies of not less than 2°C. This anomaly remains in the area not less than 4 months.

Dr. Klaus Wyrtki of the University of Hawaii indicates that El Niño is a dynamic response of the wind forces of the central equatorial Pacific. He also indicates that there exist four basic pre-El Niño conditions, essential to the development of the occurrence. They are: strong meridional winds, depression of the thermocline in the western Pacific, elevation of the sea-level and cooling of the equatorial area.

The major changes in the tropical Pacific occur between the coast of South America and 140°W, as a consequence of the cold waters of the Humboldt current coming from the south. The coastal and equatorial vertical displacements are additional reasons for the low superficial temperatures in this area. The southern equatorial current transports these waters to the west, and during this trajectory, water is heated by the atmosphere, increasing its temperature by several degrees. This entire system is fed by the southeastern tradewinds.

INOCAR and Research Regarding EL Niño Events

The Oceanographic Institute of the Navy of Ecuador has dedicated much effort to investigating this phenomenon during the last decade. Research Vessel ORION conducts periodic oceanographic research in the coastal and insular areas of Ecuador. At the same time, coastal

observation stations collect meteorological data daily, measuring temperature, salinity and tidal movements.

INOCAR also participates actively in the multi-national program "Regional Study of the El Niño Phenomenon" (ERFEM), sponsored by Colombia, Ecuador, Peru and Chile, members of the Permanent Commission of the South Pacific (CPPS).

INOCAR maintains an agreement of cooperation with the NOAA/AOML, for the execution of a program of data collection of superficial and sub-surface temperatures by commercial shipping vessels on the routes of Guayaquil to Japan and Guayaquil to the Galápagos.

The Evolution of the Warm Season Event of 1987

In August of 1986 sea surface temperatures in the Eastern Pacific indicated normal conditions. The equatorial front was located to the north of the equator. The Humboldt current was well developed and supplied cool water to the equatorial current system. To the north, in the region of Central America, the presence of small patches of water with temperatures of 28°C were registered.

In the month of October, data from drifting buoys indicated a strong current of greater than one knot in the North Equatorial countercurrent. In November, the North Equatorial countercurrent was well developed to the East of 150°W. But the most remarkable characteristic was the presence of a 1.5 knot flow in a westerly direction in the South Equatorial current between the Galápagos Islands and 150°W.

By December drifting buoy data indicated the presence of a strong North Equatorial countercurrent both in the oriental and occidental region. In the Central American region, buoys turned south and southeast in the direction of the Galápagos Islands, and reported anomalies in temperature greater than 1°C. At 2°S, between the mainland and the Galápagos, a westerly flow was still present, associated with the South Equatorial current, the activity of which could be observed until 150°W. Together with this intensification of the North Equatorial countercurrent, to the west of the dateline, strong winds from the west were registered. This probably strengthened the North Equatorial countercurrent in the Western Pacific. This characteristic was quite similar to the one observed during the 1982-83 El Niño event in its phase of formation.

During January of 1987, the surface currents of the western equatorial Pacific, returned towards the west while to the east of 130°W, water movement continued towards the east. In the area of the Panama basin, drifting buoys were observed moving on a south by southeast course. This displacement of water is evident in the distribution of surface temperatures for the first week of January, where a patch of 28°C water moves south between the mainland and the Galápagos, creating a 26°C area along the equator between the coast and 120°W. Towards the end of the month the invasion of warm water is more pronounced. A tongue of 26°C water penetrated to 12°S. At the same time an advance towards the east of warm water carried by the equatorial counter-current pushes cool water towards the coast of South America.

February presents anomalies in the form of strong western winds that pass the dateline as they move east. Distribution of surface temperatures during the first days of the month show penetrations of warm water of 28°C towards the south along 85°W, and extending along the entire coastal area to 12°S with temperatures of 26°C. To the south of 15°S continues an advance of warm water towards the east, transported by a south equatorial countercurrent. By the second half of the month 28°C water covers the entire coastal area between 15°N and 5°S while masses of 26°C water reach beyond 15°S, thus indicating an irregular rise of temperatures in the oriental margin of the equatorial Pacific.

During this same month drifting buoys located between the continent and the Galápagos turn to the NW, while the general movement of the buoys is towards the west.

During the first week of March a movement of 28°C water is observed to the south of 10°S. The following week a tongue of warm water located south of the Galápagos extends its area and moves closer to the coast, indicating the presence of a warm event in the coastal area.

With respect to the distribution of sub-surface temperatures along the route Guayaquil - Galápagos, it is evident that in February the 15°C isotherm was located at a depth of 70 meters, while in October this isotherm initiates its descent to the west of 87°W reaching a depth of 130 meters during November. By the first half of February depth increases to 180 meters and by the second half it reaches a maximum depth of 200 meters. Then during the first part of April a reverse process can be observed with the 15°C isotherm rising to 160 meters. This possibly indicates a first sign of a disappearance of warm waters from the Ecuadorian coastal area, even though in the Galápagos area the higher values observed in February (1987) are maintained (Figure 1).

Figure 1. Variations in the Depth of the 14°C Isotherm, 1986-1987.

Conclusions

The warm event of 1987 was characterized by the presence of a trans-equatorial current of tropical waters between the continent and 100°W. This current had been fed for months by the North Equatorial counter-current which supplied large masses of warm water to the region of Central America.

During March of 1987, the drifting buoys indicated an increase in strength of the South Equatorial current which together with a rise of the 15°C isotherm observed off the Ecuadorian coast may be the first indication of the end of this event of elevated temperatures.

The use of drifting buoys to track the equatorial currents did not provide any useful information on the interior part of the Galápagos area. For this reason it is recommended that flowmeters and thermographs be installed at various depths at strategic locations in the island area. This type of equipment could be complemented with meteorological apparatus installed on fixed platforms.

Variations in the Content of Nutrients in the Surface Waters in the Area of the Galápagos Islands

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This paper discusses seasonal and geographical variations in surface waters and their behavior at different depths in the area of the Galápagos. Studies were made between September 1985 and February 1986, and analysis was based on various physical and chemical parameters.

The presence of equatorial sub-superficial waters was observed to have an increased tendency to rise to the surface in September 1985 and a decreased activity in February 1986.

Analysis of the nutrients (Phosphate, Nitrate etc.) during the El Niño phenomenon 1982-83 in an area close to the Galápagos islands (85°W section), showed the content to be noticeably different from a normal year.

Data was collected during three cruises conducted by the Oceanographic Institute of the Ecuadorian Navy, aboard the Research Vessel ORION in November of 1982, September 13-23, 1985 and February 6-15, 1986. Samples for this study were collected in the areas of 85°W, 92°W and the Bolivar Channel (Figure 1).

Figure 1. Cruise Track Showing Stations Taken Along 92°W, September 13 - 23, 1985 and February 6 - 15, 1986.

Section 92°W Longitude and Bolivar Channel, Galápagos.

September 1985: The upper limit of the heterogeneous body of sub-superficial water (we consider the superficial water to be the layer between the surface of the ocean and the base of the thermocline identified with the 15°C isotherm) is bounded by the 15°C isotherm at a depth of approximately 60 meters in the north and south areas of section 92°W. The lower limit is an area of low salinity, for which no data is available due to insufficient depth of sampling (600 meters).

In section 92°W, the thermocline is located at a depth of approximately 50 meters. The layer of cold water (19°C) with a salinity of 35.4 ppt measures between 40 and 50 meters and shows a relatively high concentration of dissolved oxygen (4.5 ml/L) and a high concentration of nutrients, such as Phosphate 1.3 ug-at/L, Nitrate 0.5 ug-at/L, and Silicate 40 ug-at/L (Figure 2).

Figure 2. Vertical Distribution of Hydrographic Parameters Taken Along 92°W, September 1985.

The northern area of section 92°W (1°N) shows a strong vertical temperature gradient and low salinity which indicates a boundary with the southern waters. We find warm water with temperatures of 23°C and slightly low salinity of 34.9 ppm. The mixed layer is thinner and reaches a depth of 20 meters. Concentrations of dissolved Oxygen are lower, around 5 ml/L. Presence of nutrients also decreases, indicating values of 0.9 ug-at/l for Phosphate, 0.2 ug-at/L for Nitrate and 12.9 ug-at/L for Silicate. All these characteristics were located in the southern limit of the equatorial front, which in this part of the year normally is moving in a northern direction. (Okuda et. al. 1983).

Analyzing the vertical cuts of the different parameters in section 92°W and Bolivar Channel, we note differences between the northern and southern zones, in various ranges of depth and water movements.

Surfacing activity during this part of the year is represented superficially by warm water occupying the entire channel and the southern part of section 92°W, limited by the 15°C isotherm. Even though the surfacing water in the channel proceeds only from a depth of 100 meters, this produces a great increase in the content of nutritious salts.

Sub-superficial equatorial waters that have emigrated to the surface present a homogeneous pattern of behavior, based on analysis of the concentration of nutrients: Phosphate 1.5 ug-at/L, Nitrite 0.6 ug-at/L, Nitrate 10-15 ug-at/L and Silicate 40 ug-at/L (Stations 4 and 5). This is also typical of the area of maximum surfacing action (Figure 3).

Figure 3. Vertical Distribution of Hydrographic Parameters Taken in the Area of the Bolivar Channel, September, 1985.

There is no doubt that major primary productivity must be expected in the area of surfacing due to the affluence of nutrients, but the fact that higher values are present in this season indicates a lack of utilization, possibly due to increased velocity, more than diffusion and reproduction of phytoplankton (Manriquez et. al. 1979). For this reason, the highest rates of biological production must take place along the edges of surfacing water masses and not in their nucleus.

Surfacing in the area (Station 5) is corroborated by vertical distribution of dissolved oxygen, which shows corresponding values in surging waters beginning at 40 meters, not considering the maximum oxygen values in the top layer (0-20 meters) which is influenced by the intensity of winds, normal in this season (Figure 4).

Figure 4. Vertical Distribution of Dissolved Oxygen (ml/l) Taken in the Area of the Bolivar Channel, September, 1985.

Looking at the vertical distribution, enrichment due to supply of surfacing water in the zone south of section 92°W can be noted, probably due to the prevailing circulation in this area.

The behavior of nutritious salts and dissolved oxygen is highly variable, as can be observed in the vertical profiles, but it is noteworthy that a correlation exists between different parameters. Each variation coincides with another, a consequence of the fact that this body of water is related to the waters of the equatorial counter-current and others of different chemical characteristics. However, while being in lateral contact, they conserve their individuality.

February 1986: For February of 1986, we observed clearly defined masses of surface water, formed by equatorial superficial water, at the location 4°S to 0°. Warm water was detected with average temperatures of 22°C and salinity of 35.2 ppt. Average values for nutrients were: Oxygen 4.0 ml/L, Phosphate 1.0 ug-at/l, Nitrite 0.4 ug-L, Nitrate 10 ug-at/L, and Silicate 25 ug-at/L (Figures 5 and 6).

Figure 5. Vertical Distribution of Hydrographic Parameters Taken Along 92°W, February, 1986.

Figure 6. Vertical distribution of hydrographic parameters taken along 92°W, February, 1986.

At 1°N we find superficial tropical waters with temperatures above 24°C and with a salinity above 34 ppt, dissolved oxygen of approximately 4.5 ml/L, Phosphate 0.5 ug-at/L, Nitrite 0.2 ug-at/L, Nitrate 5 ug-at/L and Silicate 10 ug-at/L.

Unlike September 1985, when a very precisely defined area of superficial water was located, no such clearly defined characteristics existed in February. During this period no high concentrations of nutrients were present. Observing data collected at the same stations (4 and 5), results were as follows: Phosphate 10 ug-at/L, Nitrite 10 ug-at/L, Silicate 15-20 ug-at/L (Figure 7).

Figure 7. Vertical Distribution of Hydrographic Parameters Taken in the Area of the Bolivar Channel, February, 1986.

In spite of the high concentration of dissolved oxygen (0.7 ml/L) at the surface in September 1985, the oceanic-atmospheric interaction was limited to the superficial layer, due to the minor intensity of the trade winds typical of that season, and the low oxygen values beginning at a depth of 10 meters (Figure 8).

Figure 8. Vertical Distribution of Dissolved Oxygen (ml/l) Taken in the Area of the Bolivar Channel, February, 1986.

Influence of the 1982-83 El Niño Current on Nutrients at 85°W: The influence of El Niño on oceanographic conditions had its major impact in November of 1982, presenting thermal anomalies between 3 and 6°C. In the entire tested area (Figure 9), superficial tropical water masses were detected, based on salinity concentrations, but no major variations in the content of dissolved oxygen were noted. At greater depths, higher levels of salinity and elevated concentrations of dissolved oxygen were recorded, indicating the presence of the Cromwell Current (Figure 10).

Nutrients (Phosphate, Nitrite and Nitrate) suffered a notable reduction in their values during El Niño. In November of 1982 nutrient values suffered reductions of 60 to 90% from the typical figures for Ecuadorian waters. Vertical distribution of these ions show low values in the superficial layers of water, which in normal years is very thin and reaches a depth of approximately 25 meters. During the 1982-83 event, depth increased to 150 meters. This, associated with the sinking of the thermocline, had an extremely negative influence on the distribution and composition of the phytoplanktonic biomass.

Figure 9. Map Showing Positions of Hydrographic Stations Taken Near the Galápagos Islands, November, 1982.

Figure 10. Vertical distribution of hydrographic parameters taken near the Galápagos Islands, November, 1982.

Conducting a study of different parameters regarding vertical distribution in section 85°W, a complete structural change can be observed in comparison with normal years. Dissolved oxygen did not present any noticeable variations during the event. At a depth of approximately 120 meters, an elevation of 2.5 ml/L was observed, which coincided with a saline patch in the same area.

The vertical distribution for Phosphate in November 1982 was registered with a concentration of 1.0 ug-at/L at a depth of 100 meters. In normal years the same concentration is registered at 50 meters and even closer to the surface in the Galápagos Islands.

Nitrite shows concentrations of 0.2 ug-at/L at depths of 20 to 30 meters, which is an average value in superficial water in normal years. Nitrate showed concentration of 10 ug-at/L at a depth of 90 meters during the event, while normally this concentration is found at 30 meters.

Conclusions

Results from observations made in the month of September indicate that there exists an intense activity of surfacing of equatorial sub-superficial waters, typical of the equatorial sub-current, while in February a substantial decrease of this activity is noted.

On the other hand, analysis of this information indicates that during September there exists circulation or flow of superficial waters in the direction of station 5.

In the layers of sub-superficial waters a chemical balance is maintained in both periods, a consequence of little movement of the masses of water.

Based on comparative analysis of the vertical distribution we find a major reduction of concentrations of nutritious elements in the 1982 El Niño event from normal years. Parting from the euphotic zone during the same period, nutrients are present in relatively normal concentrations, which indicates that the lack of these ions is more intense in the superficial areas.

Dissolved oxygen did not present major variations during the years of the study, as El Niño maintains a concentration which is almost normal. This is probably a result of migrations of marine species with the resulting reduction of consumption of this gas. The constant movement of large water masses of the Niño-, Cromwell- or equatorial sub-current always contains a high concentration of dissolved oxygen.

It can be observed that changes in the chemistry of the ocean resulted in abnormal behavior of the marine ecosystem, which has caused an upset in the oceanic biomass, due to the imbalance of nutritious elements caused by physiological disorders. Additionally, impacts on stationary resources, such as coastal and estuarine areas, resulted.

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Biological Effects of El Niño on Marine/Maritime Species

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Since the 1982-83 event, it has been recognized that the El Niño phenomena could be one of the greatest natural perturbations affecting Galápagos marine environments. (Other natural catastrophes include volcanism).

Reductions in fur seal populations rivaled those precipitated by sealers during the 19th century. Impacts of ocean variability on primary productivity and consequently on seabirds and fisheries have long been appreciated in tropical upwelling ecosystems where El Niño events are associated with widespread kills of seabirds and collapsed pelagic fisheries. Variations in reproductive success are coupled to productivity of the ocean surrounding the Galápagos Islands. The 1982-83 event demonstrated just how dependent many maritime species actually are.

Presence of El Niño in the Galápagos is signaled by the invasion of anomalously warm water into the region, increased sea level (Figure 1), heavy rains (Figure 2), and depression of the thermocline (Figure 3) resulting in the removal of nutrient-rich water from the range of upwelling caused by local wind forcing, island wake effects and bathymetry.

Figure 1. Daily Mean Sea Level at Santa Cruz from 1981 to 1983 in Centimeters Relative to the Long-Term Mean.

Figure 2. Monthly Totals of Precipitation and Days of Rain Registered at the Charles Darwin Scientific Station in Santa Cruz. The Line Marked with Dots Shows the Averages for the Years 1979 to 1981.

Figure 3. Temperature Sections Showing Depression of the Thermocline During El Niño, 1983.

Table 1. Impacts of El Niño on the Galápagos Marine/Maritime Species

Organism		Endemic?
1. Waved Albatross <i>Diomedea irrorata</i>	0 reproductive success	X
2. Fur Seals, <i>Arctocephalus galapagensis</i>	Almost complete mortality of age classes 0-3 30% mortality of females and non territorial males 100% mortality of territorial males. Reduced birth rates and weights of newborn in reproductive season following El Niño	X
3. Sea Lions, <i>Zalophus californianus wollenbacki</i>	Death of young pups High incidence of pox disease.	X
4. Most species of Sea birds	No reproduction observed Dec 1982-Jul 1983	
5. Marine Iguana <i>Amblyrhynchus cristatus</i>	Starvation due to disappearance of usual algal food. Colonies throughout islands reduced by 45 - 70% low reproductive effort during resting season following El Niño	X
6. Hermatypic corals (<i>Pavona</i> , <i>Pontes</i> , <i>Pocillopora</i>)	Bleaching, death of corals and coral reefs. Altered marine communities.	X
7. Green Sea Urchin <i>Lytechinus semituberculatus</i>	Disappearance from most areas 0 - 30 m deep (assumed high mortality)	
8. Brown Alga <i>Blossiwillia galapagensis</i>	Die-off Disappearance	X
9. Camotillo <i>Paralabrax albomaculatus</i>	Low abundance (assume migration to deeper waters)	X
10. Several marine species with Indopacific, Panamic affinities	Redistribution throughout islands	

Observations of the impact of the 1982-83 El Niño on Galápagos marine/maritime species is found in Robinson and Del Pino (1985).

Table 1 summarizes the major findings. Presumably for most species showing adverse affects, availability of typical food resources was diminished during El Niño events. Other species, however, sharing affinities with Western Pacific and Panamic Biogeographic provinces became widely distributed throughout the Islands. Presence of sea snakes (*Pelamis platurus*) and tropical pelagic fishes such as dorado (*Coryphaena hippurus*) were notable.

While much is known about many maritime species, the interactions between such species and the marine environment has been virtually unstudied. What fish species do sea lions feed on, and in what proportion? How far do they range at sea? How well do foraging ranges and foraging trips relate to the distribution of primary productivity?

What is known about wholly aquatic marine species? For known endemics very little is known. Since some endemic species showed strong adverse responses to El Niño conditions, these populations would seem to be likely candidates for further study as the conservation of such species is a critical management concern for the Islands. Substantial scientific study of other elements of the Galápagos marine environment has been done, but not where communities may be structured quite differently from mainland counterparts. Apart from studies of *Eucidaris thouarsii* (club-spined urchin) and hermatypic Galápagos corals, there exists almost no biological or ecological data.

Among the implications that El Niño has for management of the Galápagos Marine Resources Reserve are the effects that physical processes (anomalous sea level and rainfall) have on the coast and the effects of lowered food availability, nutrient availability, and oceanographic conditions on Galápagos marine/maritime species. Some points worth considering in anticipation of future El Niño events are:

1. Coastal structures and port facilities need to be designed and situated to take into account increased sea level and anomalous swells often accompanying El Niño conditions.
2. Scientific investigations designed to study periodicity and intensity of historical El Niño events need to be supported to help plan appropriate means for dealing with such events.
3. El Niño events can severely depress population numbers of many marine/maritime species. Increased sources of mortality mediated by man's activities could be particularly serious during El Niño events. These additional sources of mortality might include introduced predators, competitors, and pathogens, and accidental chemical and oil spills.
4. Increased rainfall can carry undesired contaminants such as pesticides, herbicides, or sediments into the coastal environment at much higher rates, altering ecology of nearshore lagoons or causing additional mortality in marine communities living near such sources of input.

5. Species of importance to the artisanal fishery may undergo significant redistributions both between islands and vertically with depth. The ability to estimate these redistributions based on measurements of ocean temperature with depth or remote sensing of phytoplankton distributions could significantly aid fishermen perhaps by means of fishing advisories.
6. Understanding the effects of ocean variability or distribution of food resources (for the native fauna), fishery resources and recruitment of juveniles to the fishery is essential for effective management of the Galápagos Marine Resources Reserve.

Discussion

Might there be best-candidate marine species that could be studied in relation to El Niño and what kinds would they be? Since several endemic species showed drastic reductions in abundance during the 82-83 El Niño, these species deserve further study of their population dynamics. They include the alga, Blossiwillia galapagensis, green urchin, Lytechinus semituberculatus, and chaenopsid blenny, Acanthemblemaria castroii. Because corals too were so strongly affected, further study of these organisms is interesting and necessary both for scientific questions and for their aesthetic potential.

Would El Niño and its impact on marine/maritime species be of interest to scientists working on global studies concerning such events? Most certainly. How El Niño influences ocean variability and pelagic fisheries is just one area of interest receiving attention currently. The Galápagos lies directly in the path of El Niño development and how this affects marine/maritime species would be of interest to programs such as GOFS (Global Ocean Flux Study) and TOGA (Tropical Ocean and Global Atmosphere).

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Impact of Man and His Endeavors on the Marine Environment of the Galápagos

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1. *Generalities*

- 1.1. Man remains as a foreign agent, recently arrived to the Galápagos Islands. The lifestyle he has developed there, hardly can be considered as an adequate cultural answer to the marine and terrestrial environment of the region.
- 1.2. In order to identify the impact (negative effect) -- actual or potential -- caused by man, it is necessary to briefly review the more important biotic characteristics of the marine environment and to analyze some of the elements that would effect the environment.

2. *Biotic characteristics of the marine environment of Galápagos and their resistance to the effects of human activities.*

2.1. High diversity and abundance of species:

Comparing the peculiarities of the marine environment with those of the terrestrial environment identified as fragile due to the lack of biological diversity, we can conclude that marine environments are not by nature fragile and that they possess a high resistance to the effects of man.

2.2. High incidence of endemism:

The presence of a relatively high percentage of endemism in the organisms of the Islands points to a remarkable stability that is not affected by massive and continuous migrations. Such stability could well mean an attained equilibrium unaffected by human action at a scale such as the one maintained at present.

2.3. Regionalism among islands:

Regionalism may be a trait that makes the Galápagos overly vulnerable to human action. Based on scientific knowledge of the region, the high incidence of endemism and the regionalism among the islands, strong protective measures are required.

3. *Natural agents as primary influence on the biotic characteristics of the marine environment in the Galápagos*

The number and extent of agents that influence the development and evolution of the biota of the Galápagos can hardly be summarized. However, because the present planning engagement deals primarily with area management or spatial management, we consider the following characteristics.

3.1. Geographical situation:

The Galápagos Islands are in the privileged location of confluence of a system of marine and submarine currents, countercurrents and upwellings that offer an exclusive marine environment (70,000 km²) and great dynamism. This fact minimalizes the impact that man may cause given his potential for action in reduced areas and on a small scale.

In order to address this problem we must take into account the main actions of man and his manifestations.

- a. Resource extraction: -artisanal fisheries
 - organisms collection
 - mining (sand and rocks) and dredging
- b. Services development: -Tourism and recreation
 - Scientific research
 - Navigation
- c. Human settlements -Urbanism
 - Ports development
 - waste disposal
 - sewage disposal

3.2 Geographical isolation:

Isolation is the more outstanding reason for development of the marine environment of the oceanic islands. It is expressed by a high degree of endemism, influenced by several factors such as distance, size, situation, etc.

Considering this high degree of endemism in the Galápagos, we must confront the task of characterizing the marine environment as either fragile or stable. Is the marine environment of the Galápagos stable because it presents a high degree of endemism?

To help understand the implications of human impact we must analyze the kind of impacts that man causes:

- a. Introduction of organisms;
- b. Overfishing;
- c. Applications of non-appropriate technology;
- d. Pollution;
- e. Combination of those impacts.

3.3. Character of the Archipelago:

Scientific research benefits from the geographical isolation of the Galápagos Islands and from the fact that it is an archipelago. More than forty islands and islets, distributed in a wide area are isolated by climatic "barriers" that cause an accentuated regionalism expressed in the adaptive radiation. Such character turns the Galápagos environment into one of extreme fragility from a management perspective.

Human actions critical for the maintenance of those environments are:

- a. Introduction and dispersion of organisms into the islands (Tourism, scientific research, protection);
- b. Physical infrastructure and development (Port developments);
- c. Development of public services (Regular transportation).

So presented, the problem of how to address human impact in the coastal-marine environment of the Galápagos is not an inventory of personal criteria and appraisals, but rather becomes a major problem for administrators who lack knowledge of the problem or have poorly interpreted it.

4. *Conclusions*

- 4.1. To better plan the use and management of the environment and marine resources of the Islands, the main compromise must be to design a preventive plan of research that considers the negative effects of man and his activities on the Galápagos.
- 4.2. We do not doubt that the research activities carried on in the Galápagos have placed emphasis on controlling human activity in this delicate environment. However, much of this knowledge has not been applied or interpreted appropriately for successful management of the insular environment.

Human Influences on Marine Resources in the Galápagos: Evolution of the Human Presence

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Olaf Holm, cited in the publication by E. Perez (1984), studied samples that showed that pre-Columbian navigators from Ecuadorian coasts reached the Galápagos Islands. Archaeological artifacts, discovered on the islands, match ceramics from Manta and Santa Elena.

On the 10th of March 1535 the Archipelago was accidentally discovered by the Spanish bishop of Castilla de Oro (Panama), Fray Tomas de Berlanga. He informed King Carlos V of this event, describing the existence of strange animals and plants and the physical characteristics of the islands (Black, 1973).

Between 1684 and 1816 the islands served as a refuge for bucaneeers and pirates like Dampier, Rogers, Cowley, Cooke, Clerk and others. Many of them made reports on the flora, fauna and climate and constructed the first navigational of the area.

Beginning in 1873, the Archipelago was used as an operational center for English whaling ships. In the same year the "post-office-barrel" in Post Office Bay, Floreana, was erected. (Moore, 1980).

Notwithstanding that the islands and their resources had been used by ships and people of different nationalities, no country had claimed sovereignty over the Galápagos until the 12th of February 1835, when general Jose de Villamil took possession of the islands in Floreana, in the name of Ecuador and thereby initiated the period of colonization. Three years later, in 1835, the British sailing vessel H.M.S. Beagle visited the Archipelago with the later renowned Charles Darwin on board. He stayed five weeks in part of the Galápagos and his collections and observations served as part of the evidence that culminated in the publication of "The Origin of Species" in 1859.

Agriculture was the first important activity that developed in San Cristobal until 1904. Sugar cane plantations produced large volumes of sugar, which was exported to the continent. Although the coffee plantations are in an uncultivated condition, they are still being harvested.

The most evident human effects were and are in the terrestrial area due to the arrival of introduced species. Although knowledge of marine resources is scant, there does not seem to be much damage resulting from human activities. This is possibly because agriculture in San Cristobal developed to a not-repeated level, and later cattle-raising on Santa Cruz developed as

an economically feasible activity. From the beginning of this century the artisanal fisheries developed to their maximum, yet the activity is done at a low level in unprofessional conditions.

The economic growth of the last years, due to governmental attention as well as the increase in tourism, has caused a division in the attitudes of men towards natural resources: those inhabitants who accept the limiting factors of the Galápagos (distance, absence of technology); and the new immigrants who brought their continental cultural values. The first group, seeing the initial damages done, adapted their economic activities to basically artisanal ones, like the developed fisheries; the second tried to introduce technology and modernization of the instruments they work with, more fuel and more immigrants.

Human Impact on Marine Resources

Along with the new inhabitants came those who would eventually obtain political power in the region and are currently acting as decision makers. The livelihood of the Galápagos natives is in danger.

In February 1973 the Province of Galápagos was created. There are now 8,000 persons distributed over four islands: San Cristobal, Santa Cruz, Isabela and Floreana. The island of Baltra is an airforce base with small departments of the army and the airforce (Fuerza Aerea Ecuatoriana). Because the Galápagos has a very short human history, areas of historical interest are quite scarce. Nevertheless, possibilities for historical attractions include the barrel in Post Office Bay, Floreana, the ruins of the industry and farm in San Cristobal and the Wall of Tears in Isabela.

In areas where the increase in human population could potentially impact marine resources, the increase and ensuing effects should be analyzed. It is evident that until 1986, the major population increase was in the coastal settlement Puerto Ayora, where the tourist operations in the Archipelago are concentrated. Only since May of last year did the airliner SAN initiate regular operation, transporting passengers to San Cristobal, where the effects will be apparent later.

Future Applications of Remote Sensing in the Galápagos Marine Resources Reserve

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The use of ocean color imagery (CZCS) and satellite measurements of sea surface temperature (SST) as a management tool in the GMRR has been discussed in earlier sessions of the workshop. Specifically, CZCS imagery may be used to map historical distributions of phytoplankton pigment within surface waters and in combination with SST imagery to add insight into the dynamics of surface circulation and upwelling. Other remote sensing data and techniques exist which could be of equal value in other management aspects of the Galápagos Marine Resources Reserve (GMRR). For example, Lands at MSS (Multispectral Scanner) and TM (Thematic Mapper) imagery have been shown useful in charting bathymetry and benthic features within optically shallow water and in relating surface circulation to changes in ocean color caused by terrestrial and anthropogenic related turbidity. Yet, as useful as these remote sensing techniques are to the management of the GMRR, it is future development in remote sensing devices, data analysis techniques and permanent in situ devices, that offer the greatest potential value.

Some of the greatest management challenges for the GMRR are in relation to the dynamics of primary productivity within and around the waters of the Galápagos Archipelago. Seasonal variations in wind and currents, episodic events such as El Niño, and physical and biological processes driving the growth, redistribution, and decline of phytoplanktonic communities all play a role in primary productivity. New satellite sensors and data analysis techniques planned for the 1990's will permit the oceanographer for the first time to directly address these problems on a large scale and synoptically. Moreover, new in situ devices presently under development will enable the researcher to automatically collect needed field measurements coincident with satellite overpasses.

The most important remote sensing devices for addressing the problem of primary productivity dynamics in the Galápagos Archipelago in the future will be the Ocean Color Imager (OCI), the Microwave Scatterometer (NSCAT) planned as part of the Navy Remote Ocean Sensing System (NROSS) satellite, and the radar altimeter planned as part of the TOPEX/POSEIDON Satellite. The OCI will provide phytoplankton pigment distributions in much the same manner as did the CZCS. The difference is that the OCI will have higher signal to noise ratio and the spectral bands will be even better suited to detecting pigment concentrations.

NSCAT will be a device for mapping sea surface wind vectors. A similar device aboard the now defunct SEASAT satellite was capable of mapping global sea surface wind vectors 2 m/s and 20

degree direction, with a spatial resolution of 50 km. The most impressive feature of this device is the repeat frequency of three days. NSCAT will collect similar data but with higher design accuracies. With the TOPEX/POSEIDON radar altimeter it will be possible to map global sea level to within 13 cm. Wind speed and sea level imagery will be used as input to hydrodynamic models to predict ocean circulation.

Coincident with these new sources of remote sensing data, in situ devices are presently available that could be attached to permanent buoys throughout the Galápagos Archipelago to automatically collect necessary data. In the study of phytoplankton dynamics, such a data-buoy system should include a fluorometer to estimate chlorophyll A concentration, an acoustic doppler meter to measure local current vectors, and a temperature transducer. The buoys could be maintained with cooperation between INOCAR and the Charles Darwin Research Station, as well as any foreign institution involved in the research.

Such a project of basic research involving remote sensing and coincident field data is complicated and expensive. Therefore, it would rely heavily upon international collaboration. Ecuador must begin now to open lines of communication with foreign research communities, both at the agency level and at the individual researcher level. A positive start would be involvement in on-going global research programs such as TOGA (Tropical Ocean and Global Atmosphere) and GOFS (Global Ocean Flux Study). An initial step could best be achieved by providing scientists easy access to research facilities and sampling platforms such as those within INOCAR and the Darwin Research Station. The objective of TOGA is to further our understanding of the processes driving El Niño and the Southern Oscillation, while the objective of GOFS is to identify and quantify the role that oceans play in the global carbon dioxide budget. The second step would then be to develop collaboration programs between TOGA and GOFS, with emphasis upon how processes in the eastern equatorial Pacific relate to the global objectives of each of these projects.

It is important to realize that there are no quick solutions to the problem of attracting foreign research interest and funds. The process is on-going and long-term. The scientific community is continuously changing, and so lines of communication and efforts of collaboration must remain flexible and continuous.

Figure 1. The Effect of the 1982-83 El Niño Event Upon Equatorial Pacific SST. Cross-Hatched Areas Indicate SST of 2-6°C Higher in January, 1983 than in January, 1984. Data was collected by the NOAA polar-orbiting meteorological satellite NOAA-7 using the AVHRR Scanner and was analyzed by Richard Legeckis at the NOAA Satellite Data Information Service.

The Center for the Remote Sensing of Natural Resources' Role in the Management of the Galápagos Marine Resources

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The Center for the Remote Sensing of Natural Resources of the Military Geographic Institute (CLIRSEN) will be able to collaborate with the institutions involved in management of the Galápagos Marine Resources Reserve by using information received through remote sensing.

Equipment perspectives

CLIRSEN is currently converting the Cotopaxi station into a receiving and processing station for information obtained by a satellite (ERIS Station).

There are three objectives we hope to achieve:

1. *Obtain meteorological and oceanographic information to study factors affecting fisheries:*

The plan is to build a receiving and processing station to handle data collected by the AVHRR (Advanced Very High Resolution Radiometer), and:

- o Measure sea surface temperature (SST),
- o Study El Niño phenomenon,
- o Monitor fishing areas, especially in the open sea, and
- o Study atmospheric evolution of the tropical Eastern-Pacific.

2. *Collect satellite information for hydro-meteorological studies:*

The plan is to build up a receiving and processing station to process the data collected by the AVHRR system of the Goes-Este Satellite, primarily for meteorological studies.

Currently, the Goes-Este satellite is being used to automatically transmit data from sensors installed in the data collecting platform (DCP). Ecuador is now experimenting with six installed DCP platforms and it expects to bring up international agencies interest for the installation of new platforms.

The National Institute of Meteorology and Hydrology (INAMHI) will benefit from this automatic data system thanks to an agreement signed with CLIRSEN. Likewise, INOCAR has installed a DCP platform satellite connected in coordination with CLIRSEN.

3. *Convert Cotopaxi Station:*

This project includes installation of a station for receiving and processing data sent by LANDSAT and SPOT satellites.

In the future, this satellite information could be used in oceanographic studies, especially related to ocean color, ocean-phytoplankton-turbidity and coastal currents.

Galápagos Joint Work:

CLIRSEN could help to obtain:

- o AVHRR satellite imagery,
- o Isothermal maps - sea surface temperature (SST), and
- o Environmental parameters from data collecting systems.

CLIRSEN expects:

- o To obtain in-situ survey data to compare with information obtained by CLIRSEN.
- o That every institution should obtain a direct receiving station for information generated by CLIRSEN.

Suggestions:

- o Organize work meetings between institutions on a technical level to communicate information on activities and experiences.

CLIRSEN Mangrove Survey

Using panoramic aerial photography, photos IR. b/n, and radar imagery, CLIRSEN accomplished the identification and quantification of the mangrove areas on the continental coast. The scale used for the radar imagery was 1:100,000 and, for the photos, 1:50,000 and 1:20,000. The benefit of using radar technology is that it allows us to obtain a regional vision of the mangroves. On the other hand photos allowed a detailed study.

The use of photographic information from different years has made it easier to do a comparative study on the changes in the mangrove environment resulting from natural phenomenon, and those caused by human activities. The same technique can be used for the detection and delimitation of mangrove areas in the Galápagos Islands. In fact, it is possible to get photographs of the Galápagos and, through a photo-interpretation technique, to transfer that thematic information to a base map or photographic map of the Islands. To do this work will demand coordinating the information with CLIRSEN.

Galápagos Projects - Low Technology

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The value of high technology methods has been shown by the use of satellite observations of temperatures and chlorophyllic pigments in the area of the Galápagos Islands. Unfortunately, there is no easy access to this technology due to economic limitations.

In the area of the eastern Equatorial Pacific ocean, the following instruments for data transmission and recording are employed: drifting buoys to determine superficial currents, XBT equipment for bathythermographic profiles, and oceanographic and meteorological stations.

There are plans to use low-grade technology to monitor the Galápagos Islands. Due to their lower cost, they are economically feasible here.

It is essential that measurements taken by remote sensors be compared with in situ observations, for calibration purposes. Some projects have been realized, collecting biological and oceanographic data from the marine and coastal environment.

Scientific investigations in the Galápagos area should be directed toward increasing knowledge of present and potential changes, towards determining sources of change, and toward assessing environmental impacts. Orientation and coordination must be managed by the institution in charge of marine resources.

At present a number of projects are being conducted with the participation of several national and international institutions. These include: permanent sampling of physical parameters (superficial chlorophyll, zooplankton), studies on the effects of marine borers and recuperation of coral, observations regarding Cetaceans, and studies on the location of anchoring and diving sites. There are additional important projects that must be realized before long.

INOCAR, considering the occidental region of the archipelago as the area of major variability, plans oceanographic cruises with stations along 92°W and inside the Bolivar Channel to investigate superficial movements.

Monitoring programs from fixed stations in the ocean offer a low-cost option, and long-term observations can supply a large amount of information regarding changes in circulation. In August of 1987, a program will be started with staff and logistic support from the Charles Darwin Research Station. Temperature profiles will be taken to a depth of 70 meters. Light

penetration, chlorophyll samples, horizontal and vertical movement of zooplankton will be measured. Measurements will be taken weekly in a position SE of Academy Bay (Santa Cruz island) at an isobar of 100 meters.

To achieve an efficient base of observations, a floating platform, will be installed, from which can be collected: vertical temperature profiles, salinity, dissolved oxygen, nutrients, chlorophyll, phyto- and zooplankton. The platform would also contain flowmeters, thermographs and meteorological equipment. As the platform would be situated in an area of ship transit, mandatory signaling and lights will have to be provided.

To establish this marine platform, technical and financial assistance is required from institutions involved in this type of activity. Preliminary contacts have been established with NOAA, which is interested in collaborating with this project.

A Study of the Benthic Fauna of the Reserve Area of the Galápagos Islands¹

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A study of the benthic fauna of the GMRR (Galápagos Marine Resources Reserve) must consider the following subjects:

- o Correlation of the species of the Galápagos area with those reported from the Panamanian Province.
- o Detection of critical or weak areas needing immediate protection.
- o Identification of possible concentrations of endemic species for reasons of control and preservation.
- o Detection and identification of groups of organisms typical to areas of interest (Bolivar Channel), and their distribution by area in order to determine specific ecological positions.
- o Identification of species whose population increases during phenomena like El Niño, and their positive or negative influences on accompanying fauna.

The executive institution of such investigations would be the Oceanographic Institution of the Navy (INOCAR), with a possible source of financing being international institutions. This is a top priority and is expected to have a duration of five years.

General Objectives

- o To study the principal groups of macro- and micro-organisms typical of the insular platform of the Galápagos archipelago.
- o To relate benthic species with abiotic parameters to determine ecological areas, their abundance, diversity, distribution and population dynamics.

¹Editor's note: This paper is, in fact, a copy of a proposal for the described work.

- o To compare available information with actual conditions of the species in order to detect critical conditions, and take measures necessary for their protection.

Justification

- o The Marine Reserve Area of the Galápagos Islands was created by the national government in April, 1986. This involves governmental institutions doing research dealing with the protection of existing species in the Galápagos area.
- o Past investigations of the benthic fauna of the Galápagos area have been scarce and sporadic. There is, therefore, the necessity for up-to-date information from regular monitoring throughout the year in order to obtain a more complete evaluation of the benthic fauna. These studies would provide a base for managing this reserve with scientific criteria, considering the fact that many species are unique and endemic to the area, and, for this reason, of high scientific value.
- o Specimens collected would be exhibited by INOCAR, both for scientific purposes and public education.

INOCAR's Programs

Currently, INOCAR is conducting a program of scientific investigations: "Marine and Estuarine Ecosystems". One of these programs is the "Study of the benthic fauna of the Gulf of Guayaquil". Some of the results of these investigations have been published in the scientific journal "Acta Oceanografica del Pacifico".

This INOCAR program comprises a complete study of the benthic fauna of the continental and insular platform of Ecuador. Additionally, there is a study of the benthic fauna of the GMRR, which will be evaluated and discussed in this workshop as a contribution to the protection of this resource and in the interest of finding inter-institutional financing for the project.

Schedule of Studies

Biological Studies: Collect all existing information on previous investigations related to the benthic fauna of the insular platform of the Galápagos Islands. This includes:

- o Specific populations
- o Abundance
- o Diversity
- o Vertical and horizontal distribution
- o Dynamics of population
- o Correlations
- o Relations of existing organisms with: sediments, depth, PH, temperature, salinity, oxygen, other fauna, etc.
- o Determination of benthic resources

Geological Studies: In coordination with the division of Geology of INOCAR. This includes:

- o Granulometry
- o Contents of Calcium Carbonate
- o Organic matter

TARGET: The area of the Marine Reserve of the Galápagos Islands.

PHASES OF EXECUTION: This is a long-term project, planned in annual phases with evaluations and interpretations of results at the end of each phase.

TIMEFRAME FOR EXECUTION: January 1988 to December 1992.

INSTITUTION IN CHARGE: INOCAR

FORM OF EXECUTION: Annual phases.

COORDINATION: Domestic and foreign institutions.

- o Domestic Institutions: - University of Guayaquil
 - Charles Darwin Research Station
 - Galápagos National Park
 - Galápagos National Institute (INGALA)
- o Foreign Institution: - Institutions which will finance the project.

STAFF REQUIREMENTS: The project will initially employ three biologists and three graduate students in the Natural Sciences to operate the laboratories. They will be paid by the supporting institutions.

EDUCATION: It will be necessary to employ the services of a consultant specializing in benthic and marine sciences at the beginning of the project (two months) to improve planning. Each Ecuadorian staff member responsible for the project will undergo training during three months with specialists in the country sponsoring the project.

NOTE: At the beginning of the project, one of the biologists must spend one month in the United States collecting all bibliographical material available.

Education Links with the Marine Reserve

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With the development of the management plan for the Marine Resources Reserve of the Galápagos Islands must come a mechanism for the dissemination of information about the Reserve to the public. The interaction between Marine Reserve planners and managers and the public cannot be purely passive (e.g. dissemination of pamphlets) but should include active involvement of the public in the development of the Marine Reserve. The public can be divided into residents, tourists, scientists, and film makers.

Introducing the management plan to the residents of the islands entails approaching groups such as:

1. Fisherman/Users
2. Authorities
3. Local population

Responsibility for informing these different groups are divided. Fishermen/Users include artisanal, commercial, recreational and subsistence groups. The management of artisanal and commercial fisheries is the responsibility of Direccion de Pesca, Instituto Nacional de Pesca (National Fisheries Institute, INP) and the fishermens organization, IEP.

Recreational and subsistence fishermen are more easily informed by the Galápagos National Park (PNG), the Charles Darwin Research Station (CDRS), and the Galápagos National Institute (INGALA) as they already have well-developed ways of disseminating information.

Authorities are to be informed about the Marine Resources Reserve Management Plan by higher offices in the Government of Ecuador with assistance from PNG and CDRS. Methods of informing authorities should be in the form of meetings and forums with written reports developed from these. The authorities of the islands include municipalities, Port Captains, Police, DITURIS and the tourist agencies, INGALA, PNG, CDRS, etc.

The local population also is an important factor in the success or failure of the Management Plan. The population should be informed at all levels in the development and implementation of the Management Plan. Passive dissemination of pamphlets must also be accompanied by workshops, radio messages, publicity using audio visuals, and other activities. In addition to these short-term

actions, more long-term activities can also be planned. An Environmental Education Plan is being developed for the Park (PNG) at the present and hopefully will contain a marine component. The plan is called the "Plan General de Educacion e Interpretacion en Galápagos." Its development is being supported by a UNESCO grant for 1987. Community involvement programs should also be developed.

Pamphlets should be distributed to tourists as they get off the plane by PNG personnel. Special instructions by guides and tourist agencies would also aid in alerting tourists to the Marine Resources Reserve. Special attention should be given to briefing scientists and film-makers upon their arrival in the Galápagos. The briefing would outline how research activities are conducted within the Marine Resources Reserve.

These are guidelines, but it must be emphasized that without properly informing the public and without public participation in the Marine Resources Reserve of the Galápagos Islands the development of a management plan for the marine preserve will be ineffective.

REPUBLIC OF ECUADOR
MINISTRY OF EDUCATION AND CULTURE
PROVINCIAL DIRECTION OF GUAYAS EDUCATION

Dr. Arthur Gaines
Marine Policy Center
Woods Hole Oceanographic Institution
Woods Hole, MA 02543

Dear Sir:

With the present writing we deliver to you and through you to the organizers of the Seminar Workshop Marine Reserve Resources in the Galápagos the following conclusion:

The perceived objectives are very ambitious but we think that with the help of each of the participants, who are representatives of a great variety of institutions, the goals we are after can be fulfilled.

EVALUATION

The Seminar-Workshop was very positive and from an educational point of view, it has been advantageous for us, because we feel compelled to help fulfill the goals, such as helping to educate our students in the field of environmental education, as well as the reeducation of adults as stated by Dr. Foster. We appreciate a good organization, a lot of dynamics and scholarship in all of the participants.

RECOMMENDATIONS

It would be nice if on the next occasion educational institutions would be involved at all levels, because they are the ones with the highest overall effect.

We suggest that if the conferences are taped they should be given to Fundacion Natura. Distribute illustrated pamphlets to educational institutions (highest level).

We join the petition of Lcdo. Alvarez to reunite after a year to see the obtained results. In finishing, we would like to thank especially you and all who contributed to the development of the Seminar: as well as for having been permitted to listen and participate in the same.

With a cordial salute,

Lcda. Ligia LANDAZURI V.
Tourism Coordinator
Coastal Education
and
Lcda. Mary Bournet, Teacher

INTERNATIONAL COOPERATION THROUGH RESEARCH

LT CDR. H. A. MOREANO
DIRECTOR, INOCAR

The research INOCAR is doing in the Archipelago and in the Marine Reserve Area has been shown to you throughout the week by INOCAR's scientists. Nevertheless, I just want to summarize the projects the Institute is carrying out. First, the hydrographic surveys to update the charts of the Galápagos waters began some years ago and some new charts are now available such as those of Wreck Bay, Academy Bay, Plaza Islands, Puerto Villamil, etc. R/V ORION is presently surveying the area of Bolivar Channel, Banks and Urbina Bay, Punta Espinoza and Tagus Cove.

Secondly, oceanographic research, especially on the west side of the Archipelago (92°W), has collected almost eight years of data with the goal of understanding the upwelling and circulation problems in the area and its implication in primary and secondary productivity. The last project, started in mid-1986, includes a station just south of Academy Bay for recording biological and physical oceanographic data. This project is being coordinated with the Charles Darwin Research Station.

But the point I want to emphasize is that the information INOCAR is getting through these projects is not enough for a complete understanding of the Galápagos marine environment. This is mainly due to the lack of equipment -- which is one area where international cooperation could come in. For example, during hydrographic surveys, R/V ORION could collect seismic, magnetic and gravity data which could be useful for a better understanding of the geological setting of the Galápagos Islands. Surface and subsurface current measurements using a profiler current meter, buoys, etc. could help to improve our understanding of the physical problems, so the ship could get more assistance in providing cheaper research through cooperative programs between national and foreign institutions as INOCAR can put equipment and scientists on board and work in close cooperation with other institutions in conducting research projects in Galápagos waters.

INOCAR has some experience in this matter. A joint project was conducted with Preussag in 1983 for operation of Geometep III (Geothermal Metallogenesis East Pacific) and with the Delft Hydraulic Laboratory (Holland), for the oceanographic studies of the Estero Salado channel, a project financed by Autoridad Portuaria de Guayaquil. Both ended with success.

A project with NOAA (Atlantic Oceanographic and Meteorological LAB., Miami) is being conducted right now to take XBT profiles along the route Galápagos - Guayaquil and Guayaquil - Japan. The data is taken by ships of opportunity and I think NOAA is quite satisfied with the work done by INOCAR for almost three years.

If any foreign scientists or Institutions are interested in carrying out research in Galápagos

waters, a starting place would be to write a letter to the Director of INOCAR expressing the intent of their research. We will see if the project fits with one of INOCAR's and determine how to use the ship to get the data. This direct letter will avoid a lot of government bureaucracy.

To send equipment and instructions to INOCAR, the Institute has a Section which deals with the custom office to get gear out on time and ready for operation. NOAA has been sending XBT probes for three years with no problems. The same was true for Preussag and Delft.

I really hope that with these ideas we can enter into cooperative research in the near future at the Galápagos Marine Reserve Area.

Note: See details of R/V ORION in Appendix "A".

ACKNOWLEDGEMENTS

LT. CDR. H. MOREANO
Director - INOCAR

At the end of these four working days I think we have achieved the goals and objectives stated by Dr. Gaines at the beginning of the week. The wide variety of criteria and points of view expressed by participants will be useful for the Technical Committee to continue its work on the Galápagos Marine Reserve. Thanks to all of you for your interest in the Workshop. I would also like to thank all the people whose work has been important in contributing to the success of this meeting. Mrs. Lucia de Roca whose translation allowed mutual understanding among foreign and Ecuadorian Scientists, CPCB Galo DAVILA, TNNV Fernando ZURITA, TNCB Victor RICAURTE and Mr. Byron Cruz, who were in charge of all the details that a meeting like this demands, are all to be thanked. In addition, Miss Fatima Leon and Suzie Wong for typing the manuscripts and making them comprehensible, Mr. Cristobal Salazar for his help with the computers, Mr. Galo Garces and Galo Arana in charge of coffee and soft drinks during the breaks. Thank you.

Dr. Arthur G. Gaines
Marine Policy Center

I wish to endorse Lt. Cdr. MOREANO's acknowledgements in thanking the many people at INOCAR who made this Workshop a pleasure for us all and made it possible to attain our ambitious goal. We are grateful for the encouragement of Digeim and the Ministry of Commerce, Industry and Integration. The Workshop was supported by a grant from the U.S. National Science Foundation (International Programs section) as well as by funds from the Tinker Foundation and the Pew Foundation.

**APPENDIX A: MARINE RESEARCH PRIORITIES OF THE CHARLES DARWIN
RESEARCH STATION**
Excerpt from the 1987 Operational Plan

BACKGROUND

The agreement established in 1964 between the Ecuadorian Government and the Charles Darwin Foundation clearly delineates the Station's areas of operation in the Galápagos Islands. All the activities operate within the framework of conservation and protection. This means that there is a need for basic investigations to understand the existing problems and to find solutions for them, which often requires direct participation in management and protection which is undertaken by the GNPS. As far as it is possible, help is given so that Ecuadorian scientific institutions can carry out these investigations, participate in them, and develop investigations of their own.

The Station also offers help to foreign scientists who carry out fundamental research with their own finances. These are not included in this plan, but often they offer considerable help and produce information that serves to aid in conservation efforts.

In accordance with identified problems, four scientific departments, with a specialist in charge of each one, have been formed. The structure of the Operation Plan reflects the activities of these departments, with the order of presentation not indicating importance.

1. BOTANY. There exist very many endemic plants in the islands. However, this vegetation is also the basis for animal life. Introduced plants menace the natural systems, forestry exploitation puts pressure on indigenous and endemic trees, and the colonized zones reduce the surface area available for vegetation communities.

2. TERRESTRIAL ECOLOGY. This department covers the investigations concerning the endangered indigenous and endemic animals and their ecological requirements. Also studied are entire groups of animals (birds, invertebrates) that have been affected by "catastrophes," both natural or those caused by man, such as the fire on Isabela. Studies are carried out to monitor some introduced species which affect natural communities. In accordance with the established priorities, three sections have been defined: Entomology (Invertebrates), Herpetology (Reptiles), and Ornithology (Birds).

3. INTRODUCED MAMMALS. The very special menace that the introduced mammals present to the islands and the huge problems of their control or eradication make it necessary to create a specialized department to produce basic data on biology and distribution and to experiment, in cooperation with the GNPS, in methods of control and the monitoring of the results of the intensive and costly field campaigns which are carried out. In spite of the successes in the past, there remains much to do. The problems increase as operations concentrate on larger islands.

4. MARINE ECOLOGY. The declaration of the coastal zones as a marine resource reserve reflects the importance of marine life, sustaining a number of coastal species, many of which are endemic. A large part of the human population depends on the exploitation of marine resources (fishing, black coral exploitation), but they also depend on the sea as a means of transport. Environmental fluctuations produce changes in ecosystems and studies are needed for a better and controlled use of these resources in tourism.

5. SCIENTIFIC SUPPORT. Meteorological conditions are fundamental in the interpretation of the environment. The Station participates in the national network of meteorological stations and the international monitoring of seismic events and tides. To conduct effective conservation work, good maps on a small scale are required. The cartographer will have to divide his work among all departments.

EDUCATION

The education activities at various levels are fundamental for long term conservation. The Station has its own group to coordinate the training of Ecuadorian scientists and students, allow relevant studies to be done by people from Galápagos in Ecuadorian universities, to produce material for primary and secondary schools in the islands, and to discuss the results of specific training efforts. Public relations are fundamental for the adequate appreciation of our work.

ADMINISTRATION

An organization with more than 60 employees, amongst them many scientists and students, necessitates administrative, financial, and maintenance systems. The institution must satisfy the demand for growth in accordance with scientific and educational needs. A transport and research boat is essential in an island environment, but places a high demand on maintenance. The distance from the continent produces special problems of supplies and many services, which ought to be offered by the institution, are unavailable.

MARINE ECOLOGY DEPARTMENT

BASIC INVESTIGATIONS

An examination of the basic biotic and abiotic parameters, as well as a study of the seasonal variations and biological indicators of contamination, permit us to understand and interpret environmental fluctuations in the long term, which affect the marine life in general as well as human activities.

Although at the moment the human impact does not appear to be serious, the beginning of studies of these conditions will serve in the future as a source of data by which to judge problems and to warn management authorities when there exist clear indications of organic contamination.

With the exception of the daily reading of sea surface water temperature, collected for several years and forming part of the environmental monitoring, no other physical parameter has been regularly studied in Galápagos waters. Considering the location of the Galápagos Islands in the Pacific, the regional importance of the information generated here is evident. Therefore it is necessary to maintain various fixed stations for the regular monitoring in Academy Bay, Santa Cruz, as well as in other sites in the archipelago.

Prior to and during El Niño, the National Fisheries Institute and Duke University studied some aspects of the marine environment, including phytoplankton. We must continue to collect this data during the post-El Niño period in order to determine the variations with regard to environmental variables. Similarly, studies on zooplankton are necessary.

Sea water generally has low levels of biogenous hydrocarbons derived from petroleum. In the vicinity of a petroleum leak, and in some bays, ports, and estuaries near urban areas, a quantity of non-biological hydrocarbons are found, some of which are foreign to the aquatic organisms. The importance of these hydrocarbons may be insignificant when considered in comparison with other substances such as pesticides and PCB's. The significance of petroleum and other xenobiotic components of sea water will eventually affect man. It has been established that marine organisms are affected by hydrocarbons as they absorb them from the environment and then they are incorporated into the food web.

The majority of the subtle effects of hydrocarbons are observed in the tourist areas and in the principal ports, where bilge water from boats is washed into the water very near the coast. These effects are manifested by an immediate reduction in productivity or alteration in species composition. Since Academy Bay is an area with intensive tourist movement, it would be advisable to conduct long-term monitoring of petroleum hydrocarbons in its superficial waters.

- 541.01. Physical parameters of the waters of Academy Bay and other locations (S/258,704)
- 541.02. Study of phytoplankton in Academy Bay (S/94,700)
- 541.03. Study of zooplankton in Academy Bay (S/94,700)
- 541.04. Study on concentrations of petroleum hydrocarbons (S/136,200)

The coastal-littoral benthos (and associated demersal species) contains the marine flora and fauna of Galapagos with the greatest genetic diversity and level of endemism. This is due to isolating factors such as a short larval stage for dispersal and the mixture of populational elements. It is a food source for such important species as marine iguanas, cormorants, and sea lions. It includes the intertidal and sublittoral zones, which are those of easiest and most frequent access by man for activities such as tourism, subsistence and sport fishing, and diving. The elements of the benthos are sensitive indicators of natural environmental fluctuations and those attributable to human impact such as contamination.

The benthic algal flora in Galapagos is moderately rich, with more than 300 species and 40% endemism. The communities in the infra- and sublittoral were strongly altered by the last El Niño event. These algae are important as food and habitat for a diverse fauna. A study was begun with a teacher from the University of Guayaquil, but was discontinued in 1986 due to lack of logistical coordination. Given the scientific importance of this study, it deserves reconsideration in the Operation Plan for 1987.

Brachyurans form an important part of the littoral ecosystem. Lava crabs contribute notably as a scenic element, but in the vicinity of populated areas, they are exploited for food. Population studies were done in 1983 and 1984 and can be used as references for the changes which are occurring. For many years chitons have been the object of subsistence and sport fishing by the human population in Galapagos. The exploitation is conducted once a month, on nights of full moon, at low tide among the rocks in the littoral zone near the port. The effect of this exploitation can already be noted. Studies on these exploited populations would give a better understanding of the human impact and could provide data for potential management.

El Niño 1982-83 produced great changes in the invertebrates along the length of the Galapagos coastlines. In Academy Bay the local extinction of the sea urchin Lytechinus semituberculatus was very evident, while other echinoderms (Eucidaris thouarsii) apparently took advantage of the event and increased in density. For other species (Caenocentrotus) there is no information. During 1986 Lytechinus recuperated notably. A study of echinoderms in Academy Bay is not only interesting from a scientific viewpoint, but also because it presents the opportunity to motivate and train young high school students in the area of population dynamics, using simple methods, in easily accessible areas, and at low cost.

Wood-boring bivalve molluscs, which use cellulose as a food source, are very useful in the decomposition of wood in the sea. When these organisms attack man-made constructions, however, they cause considerable economic problems. The GNPS and the Forestry Section of the CDRS plan to promote the use of native and introduced timber species for constructions, which can include marine work. A study of the processes of decomposition, the rates, and the species involved would be a useful complement to these activities.

- 542.01. Study of the marine benthic algae in the semi-exposed coasts of Academy Bay, Santa Cruz (S/158,216)
- 542.02. Study of brachyurans and chitons on rocky coasts near population centers (S/235,772)
- 542.03. Population studies on echinoderms in the intertidal and subtidal zones of Academy Bay (S/186,468)
- 542.04. Effects of encrusting molluscs on untreated wood in Academy Bay (S/24,468)

MONITORING OF THREATENED COASTAL AND MARINE SPECIES AND CRITICAL HABITATS

The marine zones of Galápagos have been, until now, relatively little altered. An attempt is being made to maintain this by creating a special management category for the interior waters of the archipelago, without affecting man's traditional use of the area. The declaration, by Executive Decree in June 1986, of the interior waters as a Marine Resource Reserve is the first fundamental step to achieve this.

Nevertheless, there are various marine species which are already suffering from heavy exploitation. Similarly some habitats or ecosystems are particularly vulnerable and are already suffering heavy impact from human use or exploitation. There are also ecosystems which are entirely constructed and characterized by organisms which suffered seriously during the last El Niño.

One of the most important nesting areas in the Eastern Pacific for the green sea turtle (Chelonia mydas) is in the Galápagos Islands. However, the destruction of their habitat continues on Santa Cruz and wild pigs still prey on their nests at Espumilla Beach on Santiago and on Quinta Playa and Bahía Barahona on southern Isabela. The reproductive biology of these animals has been studied for several years. The marking of thousands of individuals in previous years provides an exceptional opportunity to complement long-term ecological studies.

Black coral, a coelenterate which constructs a tree-like skeleton of a protein material, is well known for its use in jewelry. Because of excessive exploitation it has become a threatened species in archipelagos such as Hawaii and in the Caribbean. It is now listed in Appendix II of CITES as a threatened species. In Galápagos this situation has not reached this critical level, but the studies of Robinson and Martínez (1983) indicate that such a possibility exists through a lack of control here. The coral is not only used for art work in Galápagos, but is exported as raw material to jewellers on the continent. Studies are needed to monitor black coral in areas which are regularly exploited. Information is needed for the elaboration of management plans.

Hermatypic corals of the genera Pocillopora, Pavona, and Porites suffered massive mortality during the period of high water temperatures of El Niño 1982-83. The existence of these corals in Galápagos is particularly interesting scientifically. Reefs and coral colonies form environments which are especially attractive as tourist sites. Their recovery after El Niño will greatly influence the distribution of this activity in the islands. The study proposed in this Operation Plan is part of a series of investigations covering the Tropical Eastern Pacific.

The majority of the island coastlines are made of basaltic rock. Relatively few beaches exist in protected bays, bordered by basaltic reefs. The production of biogenic beaches is dependent on calcareous detritus from corals, molluscs, crustaceans, and echinoderms and is very limited. Their replacement is probably slow and extends over hundreds or thousands of years. The use of sand from easily accessible beaches for construction in San Cristóbal and Santa Cruz has possibly produced the destruction for some generations of important nesting areas of green turtles. Some intact beaches exist with unique dune formations, such as Tortuga Bay, which are now experiencing an increase in recreational activity. Conservation management of areas with these characteristics is essential. On the other hand, there are tendencies to develop the tourist industry, and the beaches are presented as an attraction. A descriptive inventory must categorize the beaches for this type of use.

Present tourist activities include diving with scuba equipment and, more frequently, snorkelling. The protection of the marine area will awaken a greater interest in submarine tourism. Many diving sites are located near terrestrial visitor sites. Unregulated anchoring in these areas could cause the destruction of fragile submarine communities. At the moment there are no guides, inventories, or detailed maps of diving sites or tourist anchorages. This information must be obtained.

- 543.01. Monitoring of the impact of introduced mammalian predators on the hatching success of green turtles (Chelonia mydas)
- 543.02. Monitoring of the commercialization of black coral and elaboration of a plan for the management of its exploitation (S/231,207)
- 543.03. Study on the recuperation of reefs and dead or weakened coral colonies after El Niño 1982-83 (S/88,080)
- 543.04. Study of the structure, dynamics, and recuperation of beaches (S/290,044)
- 543.05. Exploration and monitoring of anchorages and diving sites (S/1,181,124)

MONITORING AND STUDY OF FISHERY RESOURCES

The fishing resources of Galápagos, at present exploited commercially and at a subsistence level, have been studied previously in a fisheries biology context. Notwithstanding that some aspects are already known, any long term management of the fisheries requires biological information and complementary fisheries information through exploratory fishing and sampling of the fishermen's catch. This information will allow the governmental authorities to be alerted so that they can take timely management decisions. Such monitoring is important because some endemic species are included in the catch.

The Fisheries Inspectorate of San Cristóbal has collected, in previous years, information on the catch brought in by the local fishermen. During the period 1978-81 a system was implemented to sample the catch, because it was realized that a long term study of bacalao (Mycteroperca olfax) and other species that are a part of the fisheries industry was necessary. However, in previous years there was no follow-up with the information from the catch. There were only studies concerning particular aspects of biology such as the reproduction of bacalao. It is necessary to continue and to increase the fishery biology studies, to look at the population dynamics of the species which play an important role in the coastal ecosystem. They provide a source of protein and are commercially important for the Galápagos inhabitants.

Fishing for mullet has never reached the level of importance of the bacalao fishing. It is carried out on the coast with beach nets and thus is for subsistence as well as commercial. Fisheries studies have not paid much attention to this resource. It is an important element of the sandy, littoral ecosystem, and important food for native animals, and significant for local human consumption.

The fishing and other aspects of the biology of Galápagos lobsters were studied in some detail between 1976 and 1979. Good data exist concerning the catch, the fishing effort, and the fishing intensity in coastal areas. Since 1980 many changes have occurred because of the introduction of more and more small units. Between 1981 and 1983 the boat EL SALVADOR was taking more than 90% of the lobster catch, but this boat was withdrawn in 1983. Information is lacking concerning the present lobster fishing and must be obtained to allow the necessary management of this resource.

Cetaceans (whales, dolphins, and porpoises) are, to a certain extent, exploited by man for various reasons (meat, oil, baleen, for marine parks). Some species are threatened with extinction due to over-exploitation. Others are accidentally killed in great numbers due to certain fishing methods. There is a worldwide discussion over the cessation of hunting in order to learn more about cetaceans before they are exterminated, since there is still very little known about the majority of species.

Few species occur in and around the Galapagos Archipelago and there has never been a broad study on these marine mammals here. There are some reliable observations from the archipelago, but information is not available on patterns of distribution, seasonality, migrations, which species occur and in what numbers. Occasionally cetacean strandings have provided opportunities to undertake some studies. In 1987 forms for cetacean observations will be distributed to naturalist guides and other interested people in order to be able to produce a list of the cetaceans of Galapagos and thereby establish a database of observations and, if possible, of biological information on cetaceans.

- 544.01. Monitoring and study of the local fishery and its resources (bacalao and others) (S/531,701)
- 544.02. Monitoring and study of the mullet fishery (Mugil sp.) (S/166,470)
- 544.03. Monitoring and study of the lobster fishery (S/267,981)
- 544.04. Database of cetacean observations (S/115,872)

CONSULTATION

The Ecuadorian Government, in June 1986, by means of an Executive Decree, declared all the interior waters of the archipelago as a Marine Resource Reserve. This management category, by definition, permits the establishment of different categories and levels of protection, conservation, and use of the areas affected by the law. The decree calls for the formation of a High Level Commission, within which the Station will have an advisory position. This Commission should begin the elaboration of a Management Plan before June 1987. A Technical Group, working full time and with national and international assistance, will carry out this work of elaboration.

The future management of the marine zone of Galápagos must be based on the wide knowledge of all the experiences accumulated until now on an international level. For its size the marine reserve of Galápagos is a unique case and the worldwide experiences are still relatively few and dispersed for areas of this type. Nevertheless, the integration of the available experiences should be undertaken with experts in these areas coming to Ecuador and to Galápagos, even if at an elevated cost.

- 545.01. Participation as Advisor in the High Level Commission (S/38,808)
- 545.02. Participation in the Technical Group for the elaboration of the management plan for the marine area (S/2,759,040)
- 545.03. Elaboration of projects to obtain economic support and international advice in the elaboration of the management plan (S/117,180)

APPENDIX B: CAPABILITIES OF INOCAR RESEARCH VESSELS

ARMADA DEL ECUADOR

1	Ecosonda KELVIN HUGHES MS-26F	1972
1	Bus FORD F-600 Modelo	1980
1	Camión FORD F-600 Modelo	1979
1	Camión FORD F-350 Modelo	1979
3	Camionetas FORD F-150 Modelo	1979
1	Camioneta FORD F-350 Modelo	1979 (doble cabina)
2	FORD BRONCO Modelo	1979 (doble transmisión).
1	Camioneta CHEVROLET BLAZER Modelo	1979 (doble transmisión).
2	Camionetas WHILLYS Modelo	1974 (doble transmisión).
1	Camioneta TOYOTA HI-LUX Modelo	1976
4	Trayler para movilizar embarcaciones menores	
1	Furgón.

EQUIPOS, VEHICULOS Y MATERIALES PARA TRABAJOS TOPOGRAFICOS

<u>TIPO Y CAPACIDAD</u>	<u>FECHA DE MANUFACTURA</u>
1 Raydist DRS-H alcance 240 millas.	1979
3 Decca Trisponder alcance 50 millas.	1976
1 Telurómetro CD-6 alcance 2.000 M.	1974
1 Telurómetro CA-1000 alcance 30.000 metros	1974
2 Telurómetro MRA- alcance 65.000 M	1975
1 Telurómetro MRA-5 alcance 50.000 m.	1975
1 Teodolito WILD T-3 precisión 0.1 SEG.	1977
4 Teodolitos WILD T-2 precisión 1 seg.	1976
3 Teodolitos ZEISS TH2 precisión 1 seg.	1978
6 Teodolitos WILD T-16 precisión 30 seg.	1980
2 Teodolitos WILD RDS. Precisión 30 seg.	1978
1 Teodolito ZEISS. Precisión 30 seg.	1978
1 Nivel WILDS NAK 2.	1974
1 Nivel WILD NK1	1976
1 Nivel WILD N2	1974
1 Nivel ZEISS NI1	1978
3 Altimetro THOMPSON	1973
1 Estadía Base INVAR	1970
10 Miras taquimétricas	1978
5 Miras de nivelación	1978
6 Placas de centraje	1974
2 Equipos para iluminación de teodolitos.	1978
4 Generadores de 3 Kw.	1978
40 Baterías de 12 voltios	1982
8 Carpas	1979
30 Sleeping Bag	1976
2 Ecosondas de precisión RAYTHEON DE-719B	1980
2 Ecosondas de precisión AILAS 420	1980
1 Ecosonda EDO WESTER 940-2	1973
1 Ecosonda RAYTHEON DE - 723B	1974
1 Ecosonda RAYTHEON 123	1974

ARMADA DEL ECUADOR

SISTEMA DE POSICIONAMIENTO RAYDIST

Alcance de posicionamiento aproximadamente 200 millas

Consta de las siguientes unidades:

TRANSMISOR RAYDIST	Modelo TA-1000	Serie No. 27
Voltaje de entrada 24 VDC		
RECEPTOR RAYDIST	Modelo RA-89	Serie No. 35
Voltaje de entrada 24 VDC		
INDICADOR RAYDIST	Modelo GA-62	Serie No. 41
Voltaje de entrada 24 VDC		
GRAFICADOR RAYDIST	Modelo RB-15D	Serie No. 108
Voltaje de entrada 24 VDC		
Fuente de poder Raydist modelo SA-201 Serie No. 196

ARMADA DEL ECUADOR

EQUIPOS HIDROGRAFICOS

Ecosonda Atlas Deso - 20
Tipo : AZ-1006
Serie : 1910006.0583
Frecuencia de trabajo: 33 Khz
Voltaje de entrada 24 VDC
Alcance de escala de 0-5000 mts.
Alcance práctico de 0-1500 mts.

Ecosonda DESO-20
Tipo : AZ-1006
Serie : 1910006.0644
Frecuencia de trabajo 210 Khz
Voltaje de entrada 24 VDC
Alcance de escala de 0-5000 mts.
Alcance práctico de 0-1200 mts.

Ecos onda RAYTHEON OCEANOGRAFICO
Voltaje de entrada 110VAC 60 Hz
Potencia de consumo 70 Watts
Potencia de salida 2000 Watts.
Frecuencia Standar de trabajo 12 Khz
Un Digitalizador PDD
Una Unidad de controles SP-1
Un Transceptor PIR
Un Amplificador CESP-III
Un Registrador LSR - 1811

Computador TELEDYNE GEOTECH IHSS - 100D
Voltaje de entrada 110 VAC 60 Hz
Consta de las siguientes unidades:

Grabadora KENNEDY Tipo: 800 voltaje de entrada 110 VAC 60 HZ
Impresor LA-120 voltaje de entrada 110 VAC 60 Hz
Indicador ADM - 3A
Serie N.- 515906
Voltaje de entrada 110 VAC 60 Hz
Graficador DF3 - M1
Voltaje de entrada 110 VAC 60 Hz

ARMADA DEL ECUADOR

- GRABADORA DE CINTA MODELO 9000

Tamaño real	10-1/2 pulg.
Peso	1/2 plg.
Longitud	2400 pie
Velocidad	15 plg. por segundo
Modo de registrador	NR Z1
Densidad del registrador	800 bits por pulgadas
Tiempo registrado	32 minutos
Tiempo de rebobinado	3-4 minutos
Número de vuelta	9

POTENCIA DE ENTRADA

Voltaje	105 a 125 O 210 a 250 VAC (selectable)
Frecuencia	47 a 63 Hz
Potencia	500 vatios
Dimensiones	51 x 46 x 64 cm. (20 x 18 x 25 pulgadas)
Peso	55 Kg. (120 lbs)

- PESCADO DE ARRASTRE MODELO 272 (TOWFISH)

Frecuencia de operación	105 + 10 Hz
Longitud de pulso	0.1 mseg.
Rendimiento máximo	128 db referencia 1 bar. a 1 mt.
Ancho de viga horizontal	3 db puntos 1,2°
Ancho de viga vertical	50°, inclinado hacia abajo 20°
Profundidad máxima	600 mts. (2000 pies)
Peso	25 Kg. (55 lbs)
Dimensiones	140 cm (55 pulg.) de longitud, 11,4 cm (4.5 pulg.)

- CABLE DE ARRASTRE

* Tipo	acero, doblemente brindado
Diámetro	0.95 cm. (0.375 pulg.)
Longitud	150 mts. (500 pies) o 600 mts. (2000 pies)
Resistencia	5000 Kg. (11.000 lbs)
Peso	0.35 Kg/m (0.244 lb/pie)
* Tipo	Flexible, de poco peso
Diámetro	1.2 cm. (0.50 pulg.)
Longitud	50 mts. (150 pies)
Resistencia	400 Kg. (900 lbs)
Peso	0.3 Kg/m (0.2 lbs/pie)

ARMADA DEL ECUADOR

Dimensiones 15-3/4" altura x 21-3/4" ancho x 15 1/4" profundidad
Peso 128 lbs.

SISTEMA DE MAPEO DE FONDO MARINO (SMS)

ESPECIFICACIONES GENERALES

Rango (cada lago)	100 mt.	150 mt.	200 mt.	300 mt.	400 mt.	500 mt.
Escala	1:1000	1:1500	1:2000	1:3000	1:4000	1:5000
Separación	1/400 de rango					
Peso de pescado de arrastre	1% al 45% de rango horizontal					
Velocidad del pescado de arrastre	2 a 13 nudos					

SMS MODELO 960 UNIDAD MASTER

- MECANISMO DEL REGISTRADOR SISMICO

Tipo	Digital, gráfico pintado tono gris
Ancho de línea	0.125 mm
Tamaño de punto	0.125 mm (diámetro)
Número de tono gris	16
Número de datos puntos por línea.	2.048

- FORMATO DE EXPOSICION

Mapeo de piso oceánico	20 cm de ancho
Perfil de piso oceánico	5 cm de ancho

- PAPEL REGISTRADOR

Tipo	seco, electrosensitivo
Tamaño	28 cm de ancho por 50 m de longitud
Rango dinámico	23 db desde negro a blanco (16 tonos grises).

- POTENCIA DE ENTRADA

Voltaje	105 a 125 o 210 a 250 VAC (selectable)
Frecuencia	47 a 63 Hz
Potencia	94 x 72 x 45 cm. (37 x 28 x 18 pulgadas)
Peso	75 Kg. (165 lbs).

ARMADA DEL ECUADOR

- SPARKARRAY MODELO 267-A (3 electrodos) Características de pulso

NIVEL DE ENERGIA	DURACION	FUENTE/NIVEL	ESPECTRO	FRECUENCIA
500 vatio-segundo	3 mseg.	102 db ref. 1 microbar en 1 mt.	100 Hz 2 K Hz	2 pps
8000 vatio-segundo	10 mseg.	106 db ref. 1 microbar en 1 mt.	25 Hz 550Hz 25 Hz 500Hz	0.25 pps

Dimensiones: 25 cm. (H) x 25 cm (W) x 270 cm (L)

Peso (menos cable)	7.6 Kg (30 lbs)
Peso cable	2.2 Kg/m (1.5 lbs/pie)
Longitud de cable	30 metros
Máxima velocidad de remolque	12 nudos

- HIDROFONO

Especificaciones

Potencia de entrada	Batería de +9 voltios
Sensitividad	-63 db/volt/microbar
Ancho de banda	100 Hz - 10Hz
Máxima velocidad de remolque	15 nudos
Máxima profundidad de remolque	0.30 metros (0-100 pie)

- UNIDAD DE CONTROL O BATERIA

Conductos	1
Potencia de entrada	9 VDC, 2 MA
Rendimiento impedancia	2 K OHM
Dimensiones 7.6x7.6x4.4 cm	(3x3x1.75 pulg.)
Peso	0.45 Kg (1 lb)
Rendimiento conexión	UG-109/V BNC
* Batería	9 voltios Burgueses 2 UG o equivalente
Switch on/off	si

* Baterías equivalentes
Ray-o Vac D1604
Everyready 216
Mallory MN 1604

EQUIPOS OCEANOGRÁFICOS

BATHY SYSTEMS

XBT Digital Recorder Modelo SD 783C

Información recibida: Temperatura del mar y profundidad en metros

TERMO SALINOGRÁFO INTEROCEAN

Modelo 514

Serie No. 6828173

Voltaje de entrada 110 VAC

Información recibida: SALINIDAD / CONDUCTIVIDAD DEL AGUA

CONSOLA CTD GRÜNDY Y ROSETA AUTOMÁTICA CON 24 BOTELLAS.

Voltaje de entrada 110 VAC

Indicador Digital modelo 8500

Graficador Digital modelo 5055A

Procesador de señal de rango automático Modelo 8700

Graficador modelo 3314

Registrador de datos digitales modelo 8400

Grabador KENNEDY modelo 9.800

NOTA: Esta consola efectúa el control directo sobre la roseta.

- UNIBOOM Modelo 230-1 (Unidad de pulso BOOMER)

Características de pulso

NIVEL DE ENERGIA ***	FUENTE DE NIVEL *	ESPECTRO	MAXIMA FRECUENCIA
100 vatio-segundo	95	700-1400 Hz	6 pps **
200 vatio-segundo	104	500-10000 HZ	5 pss
300 vatio-segundo	107	400-8000 Hz	3.3 pps

* Referencia a un microbar a 1 metro

** Límite impuesto para capacitores en fuente de energía

*** 0.2 microsegundo de duración

Dimensiones: 33" ancho x 23" alto x 62" longitud

Peso

210 lbs (95 Kg)

Longitud cable

120 pie (30.5 mt)

Velocidad de remolque

2 a 8 nudos

Penetración

10 - 40 metros

ARMADA DEL ECUADOR

BAE "ORION" HI-92

Buque construido por los Astilleros "ISHIKAWAJIMA HARIMA HEAVY INDUSTRIES CO. LTD. (Work 10519) e incorporado a la Armada del Ecuador el 10 de diciembre de 1981.

1.1 Descripción General

El buque está diseñado para operar en aguas oceánicas y costeras a fin de llevar a cabo trabajos de carácter oceanográfico, geofísico, hidrográfico y meteorológico. Su radio de acción y autonomía permite que sus actividades se desarrollen en aguas internacionales.

1.2 DIMENSIONES

Eslora	70.20 m.
Manga	10.70 m.
Calado	3.60 m.
Desplazamiento	1105 m.

1.3 PROPULSION

Diesel eléctrico.- Dos motores eléctricos de 350 Kw. Dos hélices de 4 aspas. Bowtruster. 3 Generadores de 600 Kw cada uno y un generador auxiliar de 200 Kw.

1.4 Velocidad y Autonomía

Velocidad máxima	12.636 nudos
Velocidad de crucero	12.0 nudos
Mínima velocidad sostenida	3.5 nudos
Autonomía	6.000 millas náuticas

1.5 Dotación

Oficiales	8
Tripulantes	25
Científicos	19

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16. Abstract (Limit: 200 words) In 1986 the Government of Ecuador established the Galápagos Marine Resources Reserve encompassing the entire Galápagos Archipelago, an area embracing 70,000 square kilometers of the Pacific Ocean and its underlying seabed. A workshop, sponsored by the National Science Foundation, was held on April 20-24, 1987, in Guayaquil, Ecuador, to address the role of scientific information in planning for the management of this new Marine Reserve. The "Scientific Research and the Galápagos Marine Resources Reserve Workshop" was jointly coordinated by the Marine Policy Center of the Woods Hole Oceanographic Institution, and the Oceanographic Institute of the Navy of Ecuador (Instituto Oceanografico de la Armada). Ten North American scholars and about thirty scholars from Ecuadorian governmental and non-governmental scientific organizations, concerned with issues related to the Galápagos, met to discuss the status of scientific information on marine areas surrounding these islands. The workshop also focused on the role this information should play in crafting a management plan that will, a) recognize and mesh with environmental realities of this complex oceanic setting, b) incorporate new scientific information as it becomes available, and c) accommodate the needs of scientists working in the remote, typically harsh and often unique setting the Archipelago provides the international academic community. Despite some important gaps, considerable scientific information is available to Reserve managers, and examples of the use of scientific information in other marine reserves is also available. Important areas of innovation are needed in order to gather and use information effectively for the management of this vast ocean area. Remote sensing technology and international cooperation offer promise in this regard.			
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