Palau Coral Reef Conference
Toward the Desirable Future of Coral Reefs in Palau and Western Pacific
July 23-26, 2003

PROCEEDINGS

PALAU INTERNATIONAL CORAL REEF CENTER
(PICRC)
Koror, Republic of Palau
Toward the Desirable Future of Coral Reefs in Palau and the Western Pacific

FIRST INTERNATIONAL CORAL REEF CONFERENCE AT
PALAU INTERNATIONAL CORAL REEF CENTER

PROCEEDINGS

Invited Papers and Abstracts

July 23 - 26, 2003

Palau International Coral Reef Center (PICRC)
Koror, Republic of Palau

This conference was jointly sponsored by:

PICRC Publication No. 04-001

132 p. ; 28 cm. -- (PICRC publication ; no. 04-001)

Includes bibliographical references.

ISBN 982-9079-01-5


QH541.5.C7i57 2004 574.526367

Conference Organizing Committee as at July 2003

Mr. Francis Matsutaro Chief Executive Officer, Palau International Coral Reef Center
Mr. Yimnang Golbuu Chief Researcher, Palau International Coral Reef Center
Ms. Carol Emaurois GCRMN Node Coordinator, Palau International Coral Reef Center
Dr. Ken Okaji Research Coordinator, Palau International Coral Reef Center

This Conference was supported by:

Japan International Cooperation Agency (JICA)
Shinjuku Mayinds Tower Bldg.
Yoyogi 2-chome, Shibuya-ku
Tokyo 151-8558, Japan

Cover designed by Mr. Jim Kloulechad (PICRC)

Proceedings compiled and edited by Dr. Hideki Yukihira (PICRC)
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preface</td>
<td>1</td>
</tr>
<tr>
<td>Palau Coral Reef Conference - Program</td>
<td>2</td>
</tr>
<tr>
<td>List of Plenary Addresses</td>
<td>4</td>
</tr>
</tbody>
</table>

## ORAL PRESENTATION SESSION 1

### Status of Reefs & Discussion: The Future Direction of GCRMN Micronesia

The role of monitoring in the conservation of coral reefs of Micronesia: How the Global Coral Reef Monitoring Network can assist

- **C. Wilkinson**  

MAREPAC Role in the Micronesian Node (MAREPAC NODE)

- **C. Emaurois**  

Status of Palau’s Coral Reefs


The Environmental Resource Management Plan of Jaluit Atoll

- **J. Bungitak**  

Status of coral reefs in Papua New Guinea

- **R. Galama**  

An integrated coral reef monitoring and assessment program for the U.S. Pacific

- **T. F. Hourigan and R. E. Brainard**  

Summary of discussions on the future of the GCRMN in Micronesia

- **C. Emaurois**

## ORAL PRESENTATION SESSION 2

### Research on Reefs and Resources

Formation process of the barrier reef flat on Palau Islands

- **H. Kayanne**  

Physical and hydrodynamic environments and related transport phenomena in coral reefs and their surroundings in Okinawa and Palau

- **K. Nadaoka**  

Coral cultivation and its application

- **L.-S. Fang**  

Development of coral reef restoration method by mass culture, transportation and settlement of coral larvae

- **M. Omori, T. Aota, A. Watanuki and H. Taniguchi**  

Bivalves associated with zooxanthellae

- **S. Kawaguti**  

Iridescence Colorations on Mantle Tissue of Giant Clam, *Tridacna crocea*

- **Y. Kamishima and S. Kawaguti**  

Sunscreen in photosymbiotic ascidians

- **T. Maruyama, E. Hirose and M. Ishikura**  

AN ACCOUNT OF THE 1976 SURVEY ON PALAU CORAL REEFS

- **K. Yamazato**
Direct and indirect effects of sedimentation on coastal reef communities

K. Fabricius

Effects of suspended and deposited red-soil particles on larval settlement of corals

S. Harii and K. Nadaoka

Effects of land use change on coastal coral reefs, Palau, Micronesia

S. Victor, Y. Golbuu, E. Wolanski and R. Richmond

Land-based activities and impacts on coral reefs and the marine environment of the Pacific islands

N. S. Tuivavalagi and R.J. Morrison

Annual Reproduction Cycle of Acanthaster planci (L.) in Palau

D. Idip Jr.

Management planning for the Rock Islands Southern Lagoon Area of Koror State, Republic of Palau

K. Chaston, I. U. Olkeriil and A. Eledui

Assessing the bioavailability of phosphorus in sediments eroded from agricultural soils to marine systems

K. Chaston, W. Dennison, P. Moody

Timing of coral spawning in Palau

L. Penland, J. Kloulechad and D. Idip Jr.

Predicting coral spawning

R. Van Woesik

Into the Depth, Investigations of the deep reef environment of Palau, 60-360 m

P. Colin

ORAL PRESENTATION SESSION 3

Reef Management Issues

Marketing information needs for marine environment and natural resource management

R. Kenchington

Resource use in Palau

A. Kitalong

The importance of incorporating public values in coastal management: A case study on public preferences for coastal resource use and attitudes towards marine protected areas in Palau

S. Long

Palau’s Nationwide Protected Areas Network: Applying Innovative Ideas for Coral Reef Conservation

A. Smith

POSTER PRESENTATION SESSION

Research on Reefs and Resources (Abstracts only)

A comparative study of adductors of a gastropoda and a bivalvia, Julia and Tridacna

A. Matsuno, C. Abe and M. Imada

The distribution of pomacentrid fishes, hermatypic corals, and marine plants in the moat of Ishigaki Island, southern Japan: capability as indicator species
for the evaluation of coral reef ecosystem

*T. Shibuno, Y. Takada, Y. Fujioka, H. Ohba, K. Hashimoto and O. Abe* 126

The role of aquarium on the coral reef conservation

*M. Nonaka and H. Yamamoto* 127


**List of Participants** 129

Throughout this table of contents underlined author, in the case of a multi authored paper, indicates the person who presented the paper at the conference.
PREFACE

Palau International Coral Reef Center had the privilege of hosting in July 2003 the first international conference on coral reefs in Palau. The conference was an attempt to bring researchers working on reefs in Palau and the western Pacific together to exchange current knowledge and research activities in three areas:

- Status of Reefs
- Research on Reefs and Resources
- Reef Management Issues

As natural and anthropogenic threats facing coral reefs continue to increase, it has become even more important to integrate the three themes to address coral reef conservation and management. The three themes of the conference reflect our view that research must be relevant and contribute to management and that management must have a solid foundation in research and current knowledge.

We are pleased to share the proceedings from the conference in this publication. We hope that this publication will contribute to both coral reef research and management in Palau and the western Pacific and guide us in designing and developing future research and management activities.

Palau International Coral Reef Center would like to thank the government of Japan through JICA for providing the support that made this conference possible. Our special appreciation also goes to all the participants, especially those who traveled long distance to Palau to attend and contribute to the conference.

Francis Matsutaro
Organizing Committee Chair, Palau Coral Reef Conference
Chief Executive Officer, Palau International Coral Reef Center
## PROGRAM

### Wednesday July 23, 2003

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:30 – 9:00</td>
<td>Registration</td>
</tr>
<tr>
<td>9:00 – 9:20</td>
<td>Opening</td>
</tr>
<tr>
<td></td>
<td>Welcome and Introduction:</td>
</tr>
<tr>
<td></td>
<td>Mr. Francis Matsutaro, Organizing Committee Chair</td>
</tr>
<tr>
<td></td>
<td>Opening remarks:</td>
</tr>
<tr>
<td></td>
<td>Mr. Tommy E. Remengesau Jr., The President of Palau</td>
</tr>
<tr>
<td>9:20 – 9:30</td>
<td>Break</td>
</tr>
<tr>
<td>9:30 – 10:00</td>
<td>Plenary Address</td>
</tr>
<tr>
<td></td>
<td>Mr. Noah Idechong</td>
</tr>
<tr>
<td></td>
<td>Member of the House of Delegates, Palau National Congress</td>
</tr>
<tr>
<td>10:00 – 10:20</td>
<td>Break</td>
</tr>
<tr>
<td>10:20 – 11:30</td>
<td>Oral Presentation Session: Status of Reefs</td>
</tr>
<tr>
<td>11:30 – 1:30</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:30 – 2:50</td>
<td>Oral Presentation Session: Status of Reefs</td>
</tr>
<tr>
<td>2:50 – 3:10</td>
<td>Break</td>
</tr>
<tr>
<td>3:10 – 4:10</td>
<td>Oral Presentation Session: Status of Reefs</td>
</tr>
<tr>
<td>4:10 – 5:00</td>
<td>Discussion: The future direction of GCRMN Micronesia</td>
</tr>
<tr>
<td>5:30 – 7:30</td>
<td>Reception</td>
</tr>
</tbody>
</table>

### Thursday July 24, 2003

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 10:00</td>
<td>Oral Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>10:00 – 10:20</td>
<td>Break</td>
</tr>
<tr>
<td>10:20 – 11:20</td>
<td>Oral Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>11:20 – 1:00</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:00 – 1:30</td>
<td>Plenary Address</td>
</tr>
<tr>
<td></td>
<td>Dr. Siro Kawaguti</td>
</tr>
<tr>
<td></td>
<td>Professor Emeritus, Okayama University</td>
</tr>
<tr>
<td>1:30 – 2:40</td>
<td>Oral Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>2:40 – 3:00</td>
<td>Break</td>
</tr>
<tr>
<td>3:00 – 3:30</td>
<td>Poster Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>3:30 – 5:00</td>
<td>Oral Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>7:00 – 8:00</td>
<td>Night Session</td>
</tr>
</tbody>
</table>

### Friday July 25, 2003

<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00 – 10:20</td>
<td>Oral Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>10:20 – 10:40</td>
<td>Break</td>
</tr>
<tr>
<td>10:40 – 11:30</td>
<td>Oral Presentation Session: Research on Reefs and Resources</td>
</tr>
<tr>
<td>11:30 – 1:00</td>
<td>Lunch</td>
</tr>
<tr>
<td>1:00 – 1:30</td>
<td>Plenary Address</td>
</tr>
<tr>
<td></td>
<td>Dr. Patrick Colin</td>
</tr>
<tr>
<td></td>
<td>Director, Coral Reef Research Foundation</td>
</tr>
<tr>
<td>1:30 – 3:00</td>
<td>Oral Presentation Session: Reef Management Issues</td>
</tr>
</tbody>
</table>
3:00 – 3:30  Closing
Closing remarks:
Mr. Francis Matsutaro, Organizing Committee Chair

Saturday July 26, 2003

9:00 – 12:00  Field Excursion 1
1:00 – 4:00  Field Excursion 2
List of Plenary Addresses

Wednesday July 23, 2003

9:30 – 10:00 Mr. Noah Idechong
Member of the House of Delegates, 6th Olbiil Era Kelulau (Palau National Congress)
Former Founding Executive Director, Palau Conservation Society
PEW Fellow 1997
Goldman Environmental Prize 1995
Member of the Science and Policy Advisory Committee, PICRC, 2000 -
Title: Building constituency for coral reef conservation.

Thursday July 24, 2003

1:00 – 1:30 Dr. Siro Kawaguti
Professor Emeritus, Okayama University
Resident Scientist at Palao Tropical Biological Station in 1936, 1939-1941
Honorary member, International Society for Reef Studies
Honorary member, Japanese Coral Reef Society
Honorary member, Zoological Society of Japan
Title: Motile zooxanthellae in reef corals and zooxanthelate bivalve molluscs.

Friday July 25, 2003

1:00 – 1:30 Dr. Patrick Colin
Director, Coral Reef Research Foundation, 1991 - present
Chief Scientist, Caribbean Marine Research Center, Bahamas,
Member of the Science and Policy Advisory Committee, PICRC, 2000 -
Title: Into the Depth, Investigations of the deep reef environment of Palau,
60-360 m.
Oral Presentation Session 1
(Wednesday July 23, 2003)

Status of Reefs

&

Discussion: The Future Direction of

GCRMN Micronesia

Chair: Carol Emaurois
**The role of monitoring in the conservation of coral reefs of Micronesia: How the Global Coral Reef Monitoring Network can assist.**

*Clive Wilkinson*
Coordinator, Global Coral Reef Monitoring Network  
c/o Australian Institute of Marine Science, P.O. Box 772, Townsville, QLD4810 Australia  
Email: clive.wilkinson@crcreef.com

**ABSTRACT**

Coral reefs throughout the world are coming under increasing pressures from damaging human activities, as well as global climate change related coral bleaching. The major direct human pressures include over-fishing, especially damaging practices like blast and cyanide fishing, as well as nutrient and sediment pollution. But 1998 was a watershed year when massive coral bleaching over a global scale also impacted on the Western Pacific. During the latter months of 1998, there was extensive coral bleaching and mortality of 90% or more on the reefs of Palau, Southern Japan, Taiwan and Northern Philippines, as well as less severe bleaching in other parts of Micronesia. This posed a large problem for governments and coral reef managers who were faced with virtually no knowledge of the previous state of most of the reefs or the capacity to assess the extent of the damage and what it may mean for the reefs, their fisheries and particularly the people in the region dependent fully or partially on coral reefs. The GCRMN promotes coral reef monitoring to collect data and information on the reefs and use patterns, as well as raise awareness on the need for improved coral reef management. The GCRMN seeks to provide governments, tertiary institutes and NGOs with the tools to assess the status of their reefs and perform socio-economic assessments of community activities and attitudes. Through the partnership with Reef Check, the goal is to also involve local communities in the monitoring of their own coral reef resources and how they interact with the reefs. These data are all fed into the global database ReefBase in Penang. The aim is to provide all stakeholders with the tools to understand what is happening to their reef resources and also to be able to make wise decisions on coral reef management. One particular developing theme is to identify those reefs for priority management based on an assessment of resilience and resistance capabilities to survive major global change damage. The GCRMN is working with other agencies like the Nature Conservancy to design monitoring and assessment that will assist mangers make the critical decisions on which to base their major management efforts.
MAREPAC Role in the Micronesian Node (MAREPAC NODE)

Carol Emaurois
GCRMN Node Coordinator, Palau International Coral Reef Center
P.O. Box 7086, Koror, Palau 96940   Email: cemaurois@picrc.org

ABSTRACT

The Marine Resources Pacific Consortium (MAREPAC) provided an excellent vehicle of opportunity for the establishment of the Global Coral Reef Monitoring Network (GCRMN) in Micronesian Region. At the time that the Palau International Coral Reef Center was designated as one of the GCRMN regional Node, MAREPAC also was just beginning to establish in Palau, Guam, FSM, CNMI and probably American Samoa. The Node Office at PICRC was established in late December 2000. The designation of the Node Coordinators for the region was made possible through the MAREPAC network. The MAREPAC NODE was coined to represent the GCRMN in the Micronesian region. The MAREPAC regional consortium is an important collaborator for the implementation of GCRMN in this region. This paper will provide background information on Marine Resources Pacific Consortium (MAREPAC) in Palau and why it should be major part of the full establishment of GCRMN in the region.

BACKGROUND

The regional consortium concept was born out of consensus among the regional managers as a timely opportunity to collectively collaborate on issues important to islanders. The first organizing meeting was held in Palau in November 1999. MAREPAC-Palau is part of this regional consortium that was established to address issues relating to marine environment. Capacity buildings for locals including grant opportunities for regional issues are some of the objectives that the consortium hoped to address within each of the members countries. The members of the regional consortium include Palau, Yap, Chuuk, Kosrae, Ponphei, Republic of Marshall Islands, Guam, Commonwealth of Northern Marianas, and American Samoa. The MAREPAC–Palau was formally organized in October 2000. The MAREPAC-Palau Board is comprised of agencies that have similar roles for conservation, protection, and management of environmental resources in Palau. In 2001, the consortium of agencies developed a 5 Years Strategic Plan with specific goals and objectives. The goals and objectives of the Plan are derived from interviews with the agencies that have addressed the issues as gaps that may play major role in the implementation of their agencies plan of work. However, due to lack of funds, expertise, or personnel they have not been able to carry out these activities. Table 1 provides details information of the MAREPAC-Palau members.

The MAREPAC-Palau membership is open to any agencies that share the same goals and objectives identified in the Five (5) Years Strategic Plan. The MAREPAC-Palau receives grants from Department of Interior (DOI) through the regional administering Office at the University of Guam (UOG). Dr. Robert Richmond at the UOG Marine Lab is the Principle Investigator for the grant. Each member countries receive equal shares of this funding from UOG. For MAREPAC-Palau, the areas of critical importance for funding eligibility are the identified objectives in the 5 Years Strategic Plan. The following tables are the summaries of the funded objectives identified in the first, second and third year of the MAREPAC-Palau Five Year Strategic Plan.
Table 1. Members of the MAREPAC-Palau Board

<table>
<thead>
<tr>
<th>Name</th>
<th>Contact</th>
<th>Telephone</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bureau of Natural Resources and Development</td>
<td>Alma Ridep-Morris</td>
<td>488-5395</td>
<td><a href="mailto:almarm@palaunet.com">almarm@palaunet.com</a></td>
</tr>
<tr>
<td>Coral Reef Research Foundation</td>
<td>Lori/Patrick Colin</td>
<td>488-5255</td>
<td><a href="mailto:crrf@palaunet.com">crrf@palaunet.com</a></td>
</tr>
<tr>
<td>Division of Marine Resources</td>
<td>Theo Isamu</td>
<td>488-3125</td>
<td><a href="mailto:theodmr@palaunet.com">theodmr@palaunet.com</a></td>
</tr>
<tr>
<td>Global Coral Reef Monitoring Network</td>
<td>Carol Emaurois</td>
<td>488-6950</td>
<td><a href="mailto:emaurois2000@yahoo.com">emaurois2000@yahoo.com</a></td>
</tr>
<tr>
<td>Koror State Rangers</td>
<td>Adalbert Eledui</td>
<td>488-2150</td>
<td><a href="mailto:rorrangers@palaunet.com">rorrangers@palaunet.com</a></td>
</tr>
<tr>
<td>Office of Environmental Response and Coordination</td>
<td>Ethan Daniel</td>
<td>488-6950</td>
<td><a href="mailto:ercpalau@hotmail.com">ercpalau@hotmail.com</a></td>
</tr>
<tr>
<td>Palau Community College</td>
<td>Patrick Tellei or Vernice Yuzi</td>
<td>488-1669</td>
<td>Tellei @belau.org or <a href="mailto:vernicey@yahoo.com">vernicey@yahoo.com</a></td>
</tr>
<tr>
<td>Palau Conservation Society</td>
<td>Jason Kuartei</td>
<td>488-3993</td>
<td><a href="mailto:pcs@palaunet.com">pcs@palaunet.com</a></td>
</tr>
<tr>
<td>Palau International Coral Reef Center</td>
<td>Francis Matsutaro</td>
<td>488-6950</td>
<td><a href="mailto:picrc@palaunet.com">picrc@palaunet.com</a></td>
</tr>
<tr>
<td>The Nature Conservancy Environmental Inc.</td>
<td>David Hinchley</td>
<td>488-2017</td>
<td><a href="mailto:dhinchley@palaunet.com">dhinchley@palaunet.com</a></td>
</tr>
<tr>
<td>Bureau of Land &amp; Survey Community Centered</td>
<td>Ann Kitalong</td>
<td>587-3451</td>
<td><a href="mailto:Kitalong@palaunet.com">Kitalong@palaunet.com</a></td>
</tr>
<tr>
<td></td>
<td>Kelly Raleigh</td>
<td>488-2332</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patricia Davis</td>
<td>488-5123</td>
<td><a href="mailto:cthree@palaunet.com">cthree@palaunet.com</a></td>
</tr>
</tbody>
</table>

Table 2. Year One Objectives (FY 2000-2001): Printed Resources

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>IMPLEMENTING AGENCIES</th>
<th>MAREPAC FUNDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repository</td>
<td>Palau International Coral Reef Center</td>
<td>√</td>
</tr>
</tbody>
</table>

8
Table 3. Year Two Objectives (FY 2001-2002): Baseline Data

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>IMPLEMENTING AGENCIES</th>
<th>MAREPAC FUNDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palau National Monitoring Network (16 sites)</td>
<td>Palau International Coral Reef Center (PICRC)</td>
<td></td>
</tr>
<tr>
<td>Sedimentation Study</td>
<td>PICRC</td>
<td></td>
</tr>
<tr>
<td>Seagrass</td>
<td>PICRC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>The Nature Conservancy (TNC), Community Centered Conservation (C3)</td>
<td>✓</td>
</tr>
<tr>
<td>Mangroves</td>
<td>PICRC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Palau Conservation Society (PCS), C3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marine Resources Department</td>
<td></td>
</tr>
<tr>
<td>Biodiversity:</td>
<td>PICRC</td>
<td></td>
</tr>
<tr>
<td>Corals, Algae, Fish Algae, sponge, other invertebrates.</td>
<td>Coral Reef Research Foundation (CRRF)</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>The Environment Inc. (TEI)</td>
<td>✓</td>
</tr>
<tr>
<td>Current Study</td>
<td>PICRC, CRRF</td>
<td></td>
</tr>
<tr>
<td>Temperature Study</td>
<td>CRRF</td>
<td>✓</td>
</tr>
<tr>
<td>Fish Spawning Aggregation</td>
<td>Marine Resources and Development (MRD), Koror State, PCS, TNC</td>
<td></td>
</tr>
<tr>
<td>Marine Lakes Monitoring</td>
<td>CRRF</td>
<td>✓</td>
</tr>
<tr>
<td>Bibliography Project</td>
<td>PICRC</td>
<td>✓</td>
</tr>
<tr>
<td>Key Marine Species Study</td>
<td>PICRC, PCS, CRRF</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Year Three Objectives (2002-2003): Community Outreach

<table>
<thead>
<tr>
<th>OBJECTIVES</th>
<th>IMPLEMENTING AGENCIES</th>
<th>MAREPAC FUNDING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring Methods within communities</td>
<td>PICRC</td>
<td>✓</td>
</tr>
<tr>
<td>Environmental Awareness Outreach to communities</td>
<td>PCS</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>PICRC</td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>MRD</td>
<td></td>
</tr>
<tr>
<td>Indicator Species</td>
<td>PICRC, C3</td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

The 5 years plan identifies the development of the repository as the objective for year one. It has been very difficult to locate documents, publications and reports on Palau regarding environment. The intent of this objective was to forged efforts of all agencies in Palau to deposit any data, documentation, publications, findings and reports etc. regarding the marine environment and related topics (air, water, land and sea) in one central location to be available for the public use. Palau International Coral Reef Center Research Library is identified here as the central location for the repository. (Table 2).

The year two objectives include standardized methods for collecting baseline data on reefs, sea grass beds, mangrove, biodiversity, current, temperature, and establishment of reef monitoring network.
These objectives were developed based on collective confirmation from the agencies that baseline data on many marine resources are not available and there should be collaborative effort to establish systems to collect the baseline data. The projects funded were Bibliography, Marine Lake Monitoring, Temperature Monitoring, Peleliu Land Crabs Survey, Dugong Habitat Research, and Development of Manual for Assessment of MPA & A Report of Ngederrak Reef MPA. (Table 3).

The year three objectives were developed for community outreach and the fish population status. The objectives focus on monitoring methods within communities, environmental awareness, and abundance and composition of fishes in near shore and off shore environments. For year three, community outreach projects funded were Ngeremduu Conservation Area, and Palau Conservation Society’s Ngerikiil Watershed Fact Sheet. Other funded projects were Koror State Marine Tour Guide Certification Program, Marine Lake and Temperature Monitoring, Reef Check Training, Fish & Wildlife Enforcement Capacity Improvement, GIS Research, and Crown of Thorns Eradication Research (Table 4).

Year 2004 is the fourth year of the 5 Year Strategic Plan The year four objectives were developed for inventories to assess economic valuation of the coastal resources to include reef, fish stocks, and sustainable take level for marine based food sources. The other major objectives for year four include GIS implementation, digitizing of aerial photos of reefs and terrestrial systems, near shore benthos mapping

For year five, the objectives center on Policies and Management, sustainable management, and establishment of new MPAs. The other objective is to have visible participation of MAREPAC-Palau in legislation; be a vocal body in public forums; participation in the establishment of Executive Orders.

The members believed that funding, training, capacity building, collaboration, monitoring, and community awareness are major part of every objectives and that they are considered an on going activities.

Table 5. Funding Level

<table>
<thead>
<tr>
<th>Year</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year One</td>
<td>$10,000</td>
</tr>
<tr>
<td>Year Two</td>
<td>$24,935</td>
</tr>
<tr>
<td>Year Three</td>
<td>$23,610</td>
</tr>
</tbody>
</table>

The funding level for the first three years of the 5 Year Strategic Plan through the regional MAREPAC consortium is shown above (Table 5). The funding has doubled from the first year fund. This has allowed us to expand the projects funded through MAREPAC.

**CONCLUSION**

For some projects, the members made decisions to approve their funding annually. These include Marine Lake Monitoring, Temperature Monitoring, Repository, Ngeremduu Conservation Area.

The collaboration of the consortium of agencies in Palau and the funding from DOI through the regional MAREPAC consortium has made it possible to implement projects that are locally driven. The impact of this network is huge for local capacity building. The GCRMN in the region must establish with the assistance from the MAREPAC funding. Both network shares the same vision, goals, and objectives.
and should work together side by side.

It is hoped that the other countries fully establish their MAREPAC Board to include development of the 5 Year Strategic Plan. The plan is very critical in terms of providing clear direction of the funding appropriation and the local issues to be addressed.

The funding may seem small, but we have been able to fund projects that are critical to our local resource managers and users with much success. This arrangement of funding could very well set an example of how collaborating agencies within a country can benefit together when they have ownership to the plan.

REFERENCES


Status of Palau’s coral reefs

Yimnang Golbuu1*, Lolita Penland1, David Idip, Jr.1, Steven Victor1, Carol Emaurois1, Jim Kloulechad1 and Ken Okaji2

1 Palau International Coral Reef Center
P.O. Box 7086, Koror, Palau 96940  *Email: ygolbuu@picrc.org
2 IMG Inc. Nurumizu 667-1, Atsugi, Kanagawa 243-0033, Japan

EXTENDED ABSTRACT

Palau International Coral Reef Center launched a nationwide coral reef monitoring program for Palau in 2001. The objectives of the program were (1) to establish permanent monitoring sites; (2) determine status of Palau’s reefs; (3) assess changes to the benthic and fish communities at each site over time; and (4) examine the recovery process at each site. The program consists of a rapid assessment of reef habitats using the spot check method and a detailed monitoring survey of benthic organisms, fish and coral recruitment.

The spot check method is a rapid qualitative assessment of bottom substrates, coral cover, and dominant lifeforms. Spot check surveys are conducted by snorkeling at each sites for about 15 minutes and making qualitative observations. Two to three representative pictures of the site are taken during the 15-minute swim. Coral cover is estimated in terms of Acropora and other corals that are not Acropora in the following categories: + = 0-5%, 1 = 6-25%, 2 = 26-50% and 3 > 50%. Sites for spot check were chosen haphazardly along the reef front at every few kilometers. The spot check method offers a great overview of the condition of Palau’s reef, but the qualitative information it provides cannot be used for quantitative analysis.

With the limitations of the spot check method, a more thorough method was necessary to obtain quantitative data on the condition of the reef. A quantitative assessment to examine temporal and spatial changes, was conducted at 14 permanent monitoring sites around Palau. The fourteen permanent sites for the detailed surveys were selected to cover all geomorphologic range of reef types and localities, from sheltered fringing reefs to oceanic atolls around Palau. Potential level of human impacts on the health of coral reef was also taken into account in the selection of sites. Currently the permanent sites are stratified and replicated within habitats, sites, depth and transects. For the western barrier reefs, there are four sites; rock island fringing reefs have four sites; east coast fringing have two sites; the patch reefs also have two sites; while the atoll and east coast barrier reefs have one site each.

Detailed surveys of benthic and fish communities were conducted using video transects and fish visual census. These surveys were conducted at 10m and 3m with five 50 m transects at each site. Fish visual census were also conducted along the transects by an observer who swam along the transect line, counting the number of fish that fall within 2.5 meter on each side of the transect, and estimating their sizes. Benthic cover surveys are conducted along the same 50 meter transect line. The observer swam approximately 70 cm above the transect line at a constant speed videotaping the transect. It takes about 5 minutes to videotape each transect. Recruitment surveys are conducted by a belt transect of 0.30 meter width by 10 meter along the same 50 meter transects. Any coral that was smaller than five centimeters in diameter was considered a recruit its size was recorded. A minimum of three transects were completed for the recruitment surveys but in some sites with few recruits, more transects could be surveyed.

A total of 217 sites were assessed by spot check method in 2001 (Fig. 1). Spot check results shows that eighty-seven percent of the sites surveyed have Acropora cover in the range of 0-5% (Fig. 2).
Sixty-eight percent of the sites surveyed had coral cover other than *Acropora* lower than twenty-five percent. Of all the sites surveyed by spot checks, only one percent of sites had *Acropora* cover greater than fifty percent and only nine percent had non-*Acropora* cover greater than fifty percent.

Fig. 1. Map of Palau showing location of spot checks marked by blue boxes and permanent monitoring sites marked by red boxes.
Fig. 2. Coral cover of reefs around Palau that were surveyed by spot checks. A total of 217 sites were surveyed by spot checks.
The results of the quantitative surveys at the permanent monitoring sites show that coral cover was highest at Nikko Bay, a fringing reef site within the Rock Islands, at the 3-meter depth (Fig. 3). At 10-meter depth both Nikko and Ngemelis, western barrier fringing reef had the highest coral. Airai fringing reef at the east coast of Palau and Ngaremlengui patch reef at the west coast had the lowest coral cover at both 3 and 10-meter depths (Fig. 3). Both Airai and Ngaremlengui are dominated by sandy bottom substrates and during windy conditions, both sites get high level of sediment resuspension.

![Bar chart showing coral cover at different sites at 3 and 10 meters depth.](image)

Fig. 3. Coral cover at established permanent monitoring sites at both 3 and 10 meter depths.
The monitoring sites were selected by reef types: Atoll; east coast barrier (E. Barrier); patch reefs (Patch); west coast barrier (W. Barrier); fringing reefs that are not protected by other reef or land (Fringing exposed); fringing reefs that are protected by reef or island (Fringing sheltered). There are significant differences in coral cover among reef types and depths. At 10 meter depth, on patch reefs coral cover were significantly lower than all the other reef types except for east coast barrier (Fig. 4). In contrast, at the 3 meter depth, both exposed and sheltered fringing reefs had coral cover that was significantly higher than other reef types (Fig. 4).

![Mean coral cover by reef types at 3 and 10 meter depths.](image)

**Fig. 4.** Mean coral cover by reef types at 3 and 10 meter depths.
There are significant differences in mean coral recruitment among the different reef types at both 3 and 10 meter depths (Fig. 5). West barrier reefs had the highest number of recruits at both 3 and 10 meter depths. There were significant differences in the number of recruits between west barrier reefs and both exposed and sheltered fringing reefs at the 3 meter depth. At the 10 meter depth, the only significant difference is between recruitment at the west barrier reefs and the sheltered fringing reefs (Fig. 5).

Fig. 5. Coral recruitment of different reef types at 3 and 10 meter depths.
There is no correlation between coral cover and recruitment at 10 (Fig. 6) and 3 meter depths. Places like Nikko Bay and Taoch that have high coral cover, but low coral recruitment. In contrast, Ngemelis and Kayangel have high coral cover and high recruitment. Airai and Ngeremlengui, which have low coral cover, also had low coral recruitment. Other places like Ngerchelong, had low coral cover but had high number of recruits. Recruitment patterns can be explained by the characteristics of the individual monitoring sites. In Nikko Bay, recruitment was low due to the lack of available substrates since all suitable substrate were covered by benthic organisms. Even though Ngemelis and Kayangel had high coral cover, there were still many suitable substrate available for recruitment. Airai and Ngeremlengui sites have low coral cover and low recruitment because both sites are dominated by sandy bottoms and rubble, which are not suitable for coral recruitment.

Fig. 6. Coral cover and recruitment rate at the 14 permanent monitoring sites.
Based on the data collected thus far, recovery of reefs is occurring as evidenced by the presence of recruits and young juvenile corals at many of the monitoring sites. However, the reefs around Palau have not fully recovered in terms of percent cover and species diversity in comparison with the reef conditions before 1998.

This monitoring program is unique in that it uses both qualitative assessment and quantitative measurements at the permanent monitoring sites. The spot checks give a good overall picture of Palau while the permanent sites provide quantitative data on specific sites. To detect temporal and spatial changes, the quantitative data are useful and for overall picture of Palau’s reef, the spot check data are utilized.

We will continue to evaluate and expand the monitoring program to ensure that it remains useful in providing important information on Palau’s reef to policy makers and decision makers. Several aspects of the monitoring program, such as addition of more sites to allow for better replication; increasing knowledge of Palau’s coral species by conducting inventory and specimen collection for hard and soft corals; and addition of a water quality component will be implemented in the coming years. Consideration of other areas in the field of traditional knowledge and socio-economic components might need to be explored for their relevance to the program. Finally we need to improve our education and communication component of the program to bring the results to the relevant stakeholders in an appropriate format.

The Packard Foundation, Palau National Government, JICA, NOAA, Shell Palau and state governments within Palau provided support for this program.
The Environmental Resource Management Plan of Jaluit Atoll

*John Bungitak*
Republic of Marshall Islands    Email: eparmi@ntamar.net

EXTENDED ABSTRACT

Name of CA

Jaluit Atoll Conservation Area (JACA)

Location

JACA is located in the Republic of Marshall Islands (RMI) in the North Central Pacific Ocean. The RMI is composed of 29 atolls and five low-lying islands. Twenty-two of the atolls and four of the islands are inhabited. The atolls are scattered in an archipelago consisting of two roughly parallel islands chains- the Western Ralik (sunset) and Eastern Ratak (sunrise) chains. The atolls extended about 1130 km from North to South. The conservation area, Jaluit Atoll is a diamond-shaped atoll located on the southern end of the eastern Ralik chain, 130 miles south west of the capital, Majuro. Also known in Marshallese language as Jalwoj, the atoll (and CA) covers a surface area of 689.74 sq. km of lagoon and 91 fringing islets having 11.34 sq. km of land area.

Boundaries

The entire Jaluit Atoll constitutes the CA - 70,100 ha. Lagoon area is 68,974 ha. Land area is 1,134 ha, comprising 91 fringing islets (SPBCP database)

Ecological features and assets

A recently completed resource survey of the area confirmed the rich and healthy status of the reefs and marine resources with many species of fish, corals, land crabs and plants still in abundance. Only trochus and commercial sea cucumber populations were found to be in critical number.

Jaluit Atoll is considered the most diverse and rich in marine life of the Marshall Island atolls. The atoll contains a highly diverse and complex lagoon, coral reefs, mangrove, and littoral vegetation ecosystems. Within them are also flora and fauna communities of mammals, birds, vegetation, and a range of marine species. The key biodiversity elements are birds, turtles, giant clams (five species are endemic and under serious threat), corals, trochus, pearl, coconut crab, sea cucumber, sponges, lobsters, reef-fish, deep-sea bottom fish and vegetation communities.

Within Jaluit, a few mangrove clusters support the community in term of food and home construction materials. Five species of mangroves are found in these stands. The lagoon of Jaluit, thanks to its four deep passes is regularly replenished with ocean planktons and nutrients, providing ideal spawning conditions for the many reef and pelagic fish species including marbled cod, skipjack, rainbow runner and others. The large size and depth of the lagoon passes allow deep-sea migratory species such as tuna to regularly visit the area. Surrounding the atoll, like all atolls, is a coral reef. The presence of many coral heads formations within the lagoon point the number of recruitment habitats for the juvenile reef
fishes as well as reseeding areas for most species of giant clams and the black lip pearl oysters. The area also hosts three different turtle species, land crabs, crayfishes, lobsters and seabird species.

**History**

As a late starter in the SPBCP, the JCA has had less assistance from the programme compared to the other CAPs. However, significant progress has been made since the commencement of work in the area. The 16 member CACC has been grouped in four separate working groups, each with a specific focus based on the main needs of the project. The four groups are (a) Environment Protection and Resource Conservation, (b) GuestHouse, (c) Tour Guiding, and (d) Handicraft Co-op. (Joe Reti 2001)

Fortunately, the project was able to be extended for another three years with funds provided by ICRAN, Fish and Wildlife Services Foundation, and Wetlands International. As a result, a Environmental Marine Resources Management Plan was completed in early 2003 and had recently been adopted by the local council.

**Goal**

To provide all stakeholders with a framework to guide environmental resource management initiatives that will assist the community to maintain healthy marine and terrestrial environments for current and future generations.

**Traditional Management Approach**

All atoll’s stakeholders share the same goal – to conserve and properly manage the atoll’s marine and terrestrial resources. It is clear that the community of Jaluit Atoll hopes to achieve this goal by utilising traditional management practices, especially the system of taboo areas called ‘Mo’.

**Resource Management Plan**

The plan reactivates the traditional conservation areas within the atoll which include fifteen (15) individual ‘Mo’ and sanctuary areas. These ‘mo’s and sanctuary boundaries have been marked with buoys for easy recognition. Latitude and longitude coordinates were also taken.

In addition, there is atoll-wide ban on certain activities which include clam harvesting for commercial and sending off island, sea cucumber, Black Pearl Oyster, shark fishing, turtle and eggs, seabird and eggs, live rock and coral collecting, aquarium fish collecting, and using of destructive fishing.
Status of coral reefs in Papua New Guinea

Rodney Galama  
Department of Environment and Conservation  
P.O. Box 6601, Boroko, National Capital District, Papua New Guinea  
Email: rjgalama@hotmail.com

ABSTRACT

The coral reefs of PNG have been relatively poorly described, and have much lower levels of formal management although there is still strong traditional management. Recent survey and anecdotal accounts indicate that most reefs in PNG are in very good condition from human activity. Over 40% coral cover is common, but this varies with location, reef types, depth and other variables. It appears that a total cover of algae above 20% is not uncommon on apparently healthy reefs in PNG. Subsistence and artisanal fishing is thought to be the predominant human activity on PNG reefs. In general, reef fish harvest are thought to be below sustainable levels, however, there is evidence of substantial overfishing on invertebrate such as sea cucumber, trochus, green snail and clams in many locations. The pressure on reefs resources in PNG will almost certainly increase as the population continues to grow, especially in large coastal towns. Fishing pressure is steadily growing but does not appear to have large impacts as yet. Attempts to assess the threats and anthropogenic impacts to coral reef in PNG are severely limited by lack of data.
An integrated coral reef monitoring and assessment program for the U.S. Pacific

Thomas F. Hourigan1, and Russell E. Brainard.2
1 NOAA Fisheries, Office of Habitat Conservation, Room 15860, SSMC-3, 1315 East-West Highway, Silver Spring, MD 20910, USA   Email: Tom.Hourigan@noaa.gov
2 NOAA Fisheries, Pacific Islands Fisheries Science Center, Coral Reef Ecosystem Investigation. 2570 Dole Street. Honolulu, HI 96822, USA   Email: Rusty.Brainard@noaa.gov

ABSTRACT

The United States National Oceanic and Atmospheric Administration (NOAA) has initiated an ambitious effort to assess and monitor the coral reef ecosystems in Hawaii and the U.S. territories in the Pacific. Working with numerous partners, NOAA uses a comprehensive, multi-disciplinary approach, linking (1) ecological assessments of reef fishes, corals, other invertebrates and marine algae; (2) habitat mapping and characterization; and (3) oceanographic processes affecting coral reef ecosystems. These assessments cover an unprecedented geographic range, including Hawaii, the Northwestern Hawaiian Islands, the U.S. Line and Phoenix Islands near the equator, American Samoa in the South Pacific, and Guam and the Commonwealth of the Northern Mariana Islands in the Western Pacific. They also encompass a range of marine ecosystems from those surrounding inhabited high islands to remote, uninhabited atolls and banks with little human influence. Initial results from monitoring and assessment cruises in the Northwestern Hawaiian Islands, American Samoa, and the U.S. Line and Phoenix Islands will be presented. These NOAA-led efforts are designed to complement grant-supported monitoring programs in Hawaii; the U.S. territories; and the Freely Associated States of Palau, Marshall Islands, and the Federated States of Micronesia. Together, these efforts represent a major U.S. contribution to the goals of the Global Coral Reef Monitoring Network.
Summary of discussions on the future of the GCRMN in Micronesia

Carol O. Emaurois
Palau International Coral Reef Center
P.O. Box 7086
Koror, Palau 96940

The Global Coral Reef Monitoring Network (GCRMN) in Micronesian Region known as MAREPAC Node includes Republic of Palau, Federated States of Micronesia (FSM), Republic of Marshall Islands (RMI), Guam, Commonwealth of Northern Marianas (CNMI), and American Samoa. The Micronesian network establishment began in January 2001. The Micronesian Network has held 2 regional workshops for the Node Coordinators in year 2002. In year 2003, the Node Coordinators were invited to attend the Palau Coral Reef Conference to present report on the status of coral reefs in their countries.

The discussions in the sessions on the Status of the Reefs led to a separate meeting amongst the Node Coordinators and others who were interested in joining the discussions on the future of the GCRMN in Micronesia. The issues covered in here are specific for the Freely Associated States (FAS), which comprised of Republic of Palau, (ROP), Federated States of Micronesia, (FSM) and Republic of Marshall Islands (RMI). The issues raised in the discussions were based on lack of funding coming from GCRMN and the expectations to produce data for the Status of Coral Reefs. The data to produce a picture of status of coral reefs is still in its developmental stage in Palau, CNMI, Guam, and American...
Samoa. The United States Coral Reef Task Force has provided much of the needed funding for Guam, CNMI and American Samoa, and recently for the Freely Associated States through the Node Office in Palau. The opening of Palau International Coral Reef Center (PICRC) in 2001 has played a very important role in the development of National Monitoring Network Program for Palau and in the future may assist the other FAS countries. Currently, PICRC receives annual funding of $450,000 from the Palau National Congress that includes funding for Coral Research and Monitoring. But for FSM and the RMI, the long term monitoring program is lacking due to shortage of funding, personnel, equipment, fuel, and local government support. However, in these jurisdictions, there is growing interest from the National Government concerning the fisheries sectors baseline data for better marine resources management.

For the last 2 years, the much-needed data for the status of coral reefs in the region has not been forthcoming. However, the reports continue to improve on other areas of marine related impacts. But again, it is most difficult to expect any data within two years on coral reef benthos and fishes, fisheries, anthropogenic threats to coral reefs biodiversity, current MPAs and Monitoring, and Conservation Management Capacity when local conditions are not yet in place to produce such reports. The expectations from outside to produce the report and the local capacity available to produce necessary data for the report is not yet fully available in some of the countries in the region. In FSM, and RMI notably, there is a need to develop long term monitoring programs, data management systems including additional trainings for monitoring and database development. A critical component of these efforts is the annual funding support to sustain these programs. In Palau, PICRC is developing a data management system for Palau National Monitoring Network Program.

One of the concerns from FSM is the need to put in place a paid Node Coordinator to facilitate the states of FSM. It is difficult to coordinate the report for FSM that comprised of 4 islands with varying degree of differences from a far. The representatives of the FSM strongly support this proposal because of the importance it places on the development of their National Longterm Monitoring Network Program. However, the funding for the initial years of this position must come from outside funding source. It is envisioned that in the future this position may be funded locally.

On the other hand, an important component of the GCRMN is the ICRI. The FAS feels that ICRI should be more visible in their support for funding for the future of GCRMN in the Micronesian Region. ICRI has access to networks, countries, funding organizations, and individuals that the FAS can benefit from. On the other hand, this is the beginning of our third year in existence as a network, and success may come in slowly.

CONCLUSION

The National Congress of the Republic of Palau is allocating half of million dollars annually for coral reef monitoring and other research on coral reefs through Palau International Coral Reef. For other countries, the commitment from the National Government maybe lacking and this definitely will take sometimes before other governments pledge commitment to support local monitoring programs. Other observation is that the vision of the International GCRMN network and objectives have not been integrated to the local plans and strategies due to lack of funding or they are not considered priority in terms of local funding availability.

However, GCRMN has forged much needed collaboration and coordination amongst the countries on the issue of the status of the reefs and a need for data for better management of the resources. It is hoped that the network will grow to be a recognized entity of people and individuals that will contribute to better understanding of the status of the reefs and related resources within the region.
Oral Presentation Session 2  
(Thursday July 24 & Friday July 25, 2003)  

Research on Reefs and Resources  

Chair: Ken Okaji (July 24) & Yimnang Golbuu (July 25)
Formation process of the barrier reef flat on Palau Islands

Hajime Kayanne
Department of Earth & Planetary Science, University of Tokyo
Hongo, Tokyo 113 – 0033, Japan    E-mail: kayanne@eps.s.u-tokyo.ac.jp

ABSTRACT

The Palau Islands reef is typified by its barrier reef system on oceanic islands. The barrier reef off the western coast of the islands stretches 120 km with a width of 1 to 3 km. The lagoon, 15 km wide with a maximum depth of 50 m, separates the islands from the barrier reef. Six drill cores on the barrier reef flat and a patch reef in the lagoon revealed the recent geological history and formation process of the barrier reef.

The present reef was formed on an antecedent rise of Pleistocene substratum with a thickness of 16 m. The present barrier reef is an increment on the Pleistocene barrier reef. During interglacial stages, this rise submerged and reef was formed on it. During glacial stages, on the other hand, the barrier reef and the lagoon bottom was completely exposed subaerially and the lagoon depression was eroded by fresh water dissolution. Both processes, reef accumulation during interglacial stages and lagoon-bottom erosion during glacial stages, have enhanced the barrier reef geomorphology. The formation of the present reef topography started about 8300 years B.P. by branching Acropora following the sea level rise during the deglaciation. The vertical accumulation rate of this facies was as high as 30m/1000 years. After 7200 years B.P., when the sea-level rise rate decreased, digitate to corymbose types of Acropora formed a rigid framework of reef crest with an accumulation rate less than 2.2 m/1000 years. The dominant living corals on the reef crest in 1991 was Acropora digitata, which matches with those forming the reef crest facies. After the formation of reef crest, waves from the out ocean has been broken at the barrier reef and the calm condition has been sustained inside the lagoon and the islands. This condition led to the construction of patch reefs in the lagoon and fringing reefs and mangrove forest along the islands.

After the bleaching event in 1998, the coverage of living corals decreased to one seventh and the dominant corals shifted to massive Porites, which is not the original dominant component species on the reef crest as shown by the geological research. The loss of A. digitata from the reef crest, which has formed the rigid structure of the barrier reef crest, would greatly degraded the potential to form reef crest breakwater. Global warming leads to bleaching, which then result in reduced potential of reefs to respond to sea level rise.
Physical and hydrodynamic environments and related transport phenomena in coral reefs and their surroundings in Okinawa and Palau

Kazuo Nadaoka
Graduate School of Information Science and Engineering, Tokyo Institute of Technology
O-okayama, Meguro-ku, Tokyo 152-8552, Japan
Tel +81-3-5734-2589, Fax +81-3-5734-2650, Email: nadaoka@mei.titech.ac.jp

ABSTRACT

The Ryukyu Islands, which are located at the southwestern part of Japan and mostly encompassed with well-developed fringing reefs, have been subjected to various land-based environmental impacts such as sediment pollution. Besides, mass coral bleaching, which occurred globally in 1998, was observed also in the Ryukyu Islands. For proper understanding of these threats, we need to investigate physical and hydrodynamic environments and related transport phenomena in coral reefs and their surroundings including adjacent watersheds.

First, some recent examples of the studies by the author’s research group will be briefly introduced for the following subjects:

1) Development of a distribution-type numerical simulation model for evaluating soil erosion and discharge from a watershed based on physical modeling of plant canopy layer on soil surface and remote sensing of vegetation and soil parameters.

2) Development of new optical models for coral reef remote sensing and applications to detect spatial distributions of coral branch density, water depth, sediment coverage, etc.

3) Intensive field surveys on physical and hydrodynamic environments in a fringing reef at Ishigaki Island, Okinawa and development of hydrodynamic model to compute currents in a fringing reef, for which the bathymetry is estimated by applying the above-mentioned optical model to Ikonos high-resolution imagery.

4) A comprehensive and intensive survey to clarify the long-distance dispersal process of coral larvae from the Kerama Islands to the mid- and south-west coasts of Okinawa Island, by HF ocean radar measurement, direct larval tracking using newly developed GPS-installed drifters, aerial photographing of coral slicks, plankton netting around the drifters, etc., as well as laboratory experiments on larval crawling and settlement.

Then the results of our field survey conducted at Palau from March 26 to 30, 2001 will be shown, in which we could clarify the characteristic features of the vertical distributions of the water temperature, salinity, turbidity, Chl.a and horizontal velocity in the lagoon and at outer sea, and those of the time variations of the water temperature, salinity and velocity at several locations in the lagoon. With these, we found that the intrusion of the outer seawater around the pycnocline into the lagoon through the West Pass may contribute for the formation of the bottom-layer water mass in the lagoon, although the inflow of the outer seawater across the barrier reef into the lagoon during flood tide may also be possible. Resultant vertical stratification of the water temperature and salinity may cause the complicated features in the velocity profile in the lagoon. All these results suggest that for proper modeling of the transport and circulation phenomena within and near the lagoon we need to take account of the effects of intrusion of the outer sea.
water through the big channels into the lagoon in addition to that across the barrier reef, and of the resultant complicated three-dimensional distributions of the water temperature, salinity and currents in the lagoon.

Finally, a desirable future research plan on physical and hydrodynamic environments and related transport phenomena in the lagoon and its surrounding areas in Palau will be discussed.
Coral cultivation and its application

Lee-Shing Fang
National Museum of Marine Biology and Aquarium
2 Houwan, Checheng, Pingtung 944, Taiwan, ROC  Email: lsfang@nmmba.gov.tw

ABSTRACT

Corals around the world are severely damaged from human activity and climate abnormality. It was estimated 27% of world coral was destroyed, 32% is severely threatened, and the rest is also under improperly disturbance. However, the demand of coral from public and private aquarium, the development of coral reef tourism is ever increasing. Therefore, an active way of coral cultivation to replenish the market, to restore the damaged reef in the field, or even create underwater tourism spots to relieve the pressure from nature reef should be a fundamental way to solve the problem.

In the National museum of marine biology and aquarium, we first studied the coral growth and reproductive pattern in the field, then, developed a system as nature as possible to culture coral in the aquarium. We are able to raise more than 100 species in the live tank. The artificial coral reef ecosystems, from a few gallons to quarter of a million gallon water volume, are all both successfully maintained for more than two years. Further more, we are able to reproduce many coral species sexually or asexually in the laboratory. With these results, it is suggested that a practically way of coral cultivation for commercial supply, reef restoration and even underwater gardening for marine ecotourism are all possible with proper planning.
Development of coral reef restoration method by mass culture, transportation and settlement of coral larvae

Makoto Omori 1, Toru Aota 2, Akira Watanuki 2 and Hiroki Taniguchi 1

1 Akajima Marine Science Laboratory, Aka, Zamamison, Okinawa, 901-3311 Japan.
Corresponding author: M.O.  E-mail: makomori@amsl.or.jp
2 TETRA Co. Ltd. TETRA Technical Research Institute, Higashinakanukicho, Tsuchiura, Ibaraki, 300-0006 Japan.

Keywords: Coral reef, restoration, mass culture

ABSTRACT

We report the first of a series of experiments on coral recruitment by in situ mass culture, transportation and settlement of reef-building coral larvae in Okinawa, Japan. In May 2002, gametes and embryos were collected from a surface slick after mass spawning and reared at Akajima Island, the site of the culture experiment. Planula larvae were raised in floating culture ponds for 36-hrs prior to transportation to Naha Port, the site of the sowing experiment. Approximately 1.64 \times 10^6 larvae were transported at densities of 2000-4000 individuals/litre for three hours with little mortality. In June 2002, additional gametes were collected from branches of corals. The gametes were fertilized and cultured in a 1-ton rearing tank, and 260 \times 10^3 larvae were transported to the Naha Port. Both groups of larvae were released over concrete test blocks that were surrounded by vinyl fabric with mesh window or a nylon net enclosure to prevent dissipation of the larvae. The enclosure was removed after the larvae had settled. The number of polyps on the test blocks was monitored 3, 6 and 8 months after release. The corals were found to be growing normally. These results demonstrate that the restoration of degraded coral reefs in areas where natural recruitment is limited can be achieved through mass culture, transportation and settlement of larvae from healthy reefs.

INTRODUCTION

Coral reefs in the Okinawa Islands, Japan, are still being degraded due to coral bleaching, predation by crown-of-thorns starfish, sedimentation from land development and other human activities.

In order to restore the health of the reef, two methods of coral restoration are currently being developed at the Akajima Marine Science Laboratory: 1) the enhancement of coral recruitment by means of mass spawning, and 2) the re-plantation of corals by means of asexual reproduction. Here, we report the first of a series of experiment by in situ mass culture, transportation and settlement of reef-building coral larvae.

Akajima Island was chosen as the source of the coral planulae larvae for the restoration of coral communities around Naha Port in the Okinawa main island because the small genetic differences between corals from Akajima and Okinawa main island (Nishikawa et al. 2003) support the assumption that the planula larvae are normally transported from Akajima to Okinawa main island by ocean current (Kimura et al. 1992, Nadaoka et al. 2002).
METHODS

At Akajima Island, many hermatypic coral species reproduce simultaneously in a mass spawning event in early summer, near the time of the full moon. The gametes form “slicks” up to a few kilometers long on the surface of the water. On May 28, 2002, the majority of the acroporids in the Akajima area spawned between 21:30 and 22:30 hr, causing large slicks containing billions of gametes and embryos to form near the island. We collected the slicks by hand-scoop and transferred them to the site of the culture experiment at Akajima. The planula larvae were reared in 8 floating culture ponds until they were ready for transportation.

The culture pond is made of a nylon-reinforced vinyl fabric with a capacity of 4 m$^3$ (Fig. 1). We placed a gentle showering hose around the inside of the pond so that the larvae would not be caught on the fabric of the pond. Four ponds were positioned within a 16 m$^2$ iron raft frame that was held above the surrounding water by floats. Nylon mesh (125 um) windows (150 mm x 300 mm) on four sides and one window (300 mm x 300 mm) of the same mesh aperture on bottom allowed for the flow-through seawater exchange. Fresh seawater from 1-m depth outside the pond was provided from the showering hose throughout the experiment by a submerged pump, yielding approximately 1-ton/hr of water exchange (Fig. 2).

Figure 1. Floating culture pond
The water in the culture pond was well mixed. Differences of the temperature between the surface and bottom and between the inside and outside of the pond were always less than 0.3°C.

The number of coral eggs and embryos originally transferred into each pond was not counted. However, the density of planula larvae was monitored 19, 24 and 36 hours after spawning. Ten replicate samples (50 ml each) were taken from each pond after the pond water was rigorously stirred to remove any stratification of the developing coral larvae. The number of larvae was counted using a dissecting microscope.

Initially, we planned to rear the larvae for 4 to 5 days until they were competent to settle onto the substratum. However, because of an approaching of typhoon, we had to discontinue the rearing 36 hours after spawning. Approximately about 1.64 x 10⁶ larvae in fifty 20-litre soft polyethylene containers (2000-4000 inds/litre) were transported by boat and car to the site of sowing experiment at Naha Port, about 50 km east of Akajima.

At 36-hrs, the planula larvae were ciliated and did not die if they contacted surface of the container during transport. Mortality rate was not determined, but seemed to be little for up to 3 hours transport. Soft polyethylene container was most convenient because the larvae could be released by a diver at the site of the sowing experiment by inverting the container underwater.

On June 24 and 26, 2002, small scale spawning event occurred in the Akajima area. However, as we could not find slicks, we used gametes released from branches of Acropora tenuis that had been brought from the field to the laboratory a few days before the spawning, and fertilized them in a 1-ton rearing tank (Fig. 3). The planulae were reared for 80 to 128 hours, and about 260 x 10³ larvae were transported to Naha Port.
The Naha Port site of sowing experiment was 4 m depth and consisted of low-relief areas of limestone substrate. The site was chosen for restoration because, prior to the mass bleaching event in 1998, large patches of live coral were prevalent.

We placed 2 concrete test blocks (1-ton type X block, 1.30 m x 1.30 m x 0.44 m, Fig. 4) backside of the breakwater and surrounded them by vinyl fabric with a large nylon mesh window (125 um). The larvae were released over the test blocks. In June, 0.2 mm-mesh nylon nets enclosed the larvae in order to surely prevent dissipation of the larvae (Fig. 5). The vinyl fabric and net enclosures were removed after the larvae had settled.

The number of polyps on the test blocks was monitored 3, 6 and 8 months after sowing, and compared with that on the control block of the same dimension set outside of the enclosure.

Water temperature at the sowing site was monitored from May 23 to August 25, 2002, using a memory fitted TidbiT. It varied between 22.5 and 29.8°C, suggesting favorable condition was kept for the corals during the experiments.
Figure 4. Enclosure and concrete test block at the site of sowing experiment

Figure 5. Schematic diagram of the net enclosure
RESULTS

The larval mortality rate in the culture ponds was 8 times higher between 19 and 24 hrs (0.082 inds/hr) than between 24 and 36 hours (0.010 inds/hr) after spawning. A mean of 145 inds/litre, or 50% of the stock at 19 hours, remained at 36 hours after spawning (Fig. 6).

A total of 98 colonies were counted on vertical and oblique faces of the test blocks 8 months after the sowing (Fig. 7). They were found to be growing well. No colonies were found on the horizontal faces. No polyps were found on the control block after 3 months indicating poor natural recruitment in the Naha Port area.

Figure 6. Temporal variation of mean density (1SD) of live coral larvae in the culture pond

Figure 7. Coral colonies of 8-month old on the concrete test block
DISCUSSION

A similar experiment has been attempted in Australia with success (Heyward et al. 2002). The larval survival rate was constant through time, with a pond mean of 5% of the original stock (1.5 days after spawning) surviving to 6 days.

We conducted the experiment in June 2003 using the same culture ponds with eggs and embryos collected from slicks at Akajima. The planula larvae were kept for 3.5 days when some larvae were competent to settle on substratum. Temporal variation of mortality rate after 16 hour was similar to the present result in 2002. However, the mortality rate during the first 16 hours after spawning was considerable (0.058 inds/hr). Particularly it was 0.231 inds/hr between 12 and 16 hours, probably because of rapid dissolution of unfertilized eggs during this period (data not shown). In summary, a mean of about 200 inds/litre, or 7% of the original stock survived to 3.5 days.

None of polyps remained on the horizontal crown surface of the test blocks 3 month after the sowing. This is due probably to the heavy sedimentation of silt over the polyps. Particularly, typhoon approached to Naha Port on June 30, 2002, caused suspension of mud in water and subsequently the horizontal surface was covered by 5 mm thick of silts.

We have demonstrated that wild-caught coral eggs and embryos after the predictable annual spawning events provide a viable source for mass culture of larvae. In the fringing reefs such as of Akajima, waves often wash slicks ashore. Natural loss of eggs and embryos by various factors such as stranding, dispersion and predation is tremendous. This method allows some of these larvae that would be lost to be used for restoration. The reared larvae can be deployed in a controlled way to artificially enhance coral recruitment in situ.

The present results demonstrate the potential of this restoration method to the rehabilitation of coral reefs in areas where natural recruitment is limited. In the future, large-scale slick sampling, mass culture, transportation and installation of polyps-attached substrates should be feasible with the knowledge of spawning times and conditions favorable to slick formation. The success of this restoration method will be enhanced by optimizing the physical and biological factors critical to the growth and survival of juvenile polyps.

ACKNOWLEDGEMENTS

We thank N. Hirose, M. Kuchinomachi and S. Shibata for their assistance in the field. Zamami Fishing Union cooperated for establishment of the floating culture ponds. The Technology Development Fund of the Ship and Ocean Foundation supported this study. Research at the Akajima Marine Science Laboratory was partly covered by grants from the Nippon Foundation. We are indebted to their thoughtfulness.

LITERATURE CITED


Bivalves associated with zooxanthellae

**Siro Kawaguti**  
Professor Emeritus, Okayama University, Japan.  
1-6-20 Tsuhima-Fukui, Okayama 700-0080, Japan

**ABSTRACT**

In the summer of 1936, the writer visited the Palao Tropical Biological Station for an ecological study of reef corals. Soon after the beginning of field works, he observed motile zooxanthellae in branches of Acropora or Montipora which were brought into the laboratory for a further observation and were kept in a kitchen enamel bowl, not in an aquarium.

Then, he looked around for animals associated with zooxanthellae on a reef flat exposed in low tides and met with Corculums. Corculums appeared in extensive variations. He applied electron microscopy for this study and revealed real relations between zooxanthellae and host cells.

After 1954, he traveled to the Amami Islands, most frequently to Kikai Jima, and studied regional variations in zooxanthellate bivalves. Individual modifications were also indicated in mass culture samples.

He turned to Okinawa in 1970 and found Fragum unedo and F. frafum in Ishigaki Island. These two fragum shells suggested ways of researches, and some zooxanthellate bivalves were found.

Distribution of these zooxanthellate bivalves in geological history were expressed in a figure with those of Tridacnid and associated precursors. Corculum appeared in various forms as described above within only recent 10,000 years.
Iridoscent Colorations on Mantle Tissue of Giant Clam, *Tridacna crocea*

Yoshihisa Kamishima and Siro Kawaguti
Department of Human Nutrition, Faculty of Contemporary Life Science, Chuugokugakuen University, 83 Niwase, Okayama 701-0197, JAPAN

**INTRODUCTION**

Giant clams are dominant bivalves in coral reef waters and cultured as fishery products in tropical islands. The clams are known to have successful symbiotic establishment with photosynthetic algae (1), so that they can thrive in poor nutrient tropical waters under the rich solar ray. This is one of reasons the clam culture is successfully popular in the Palau islands. One of characteristic features of the genus is brilliant coloration on its mantle tissue as well as the gigantic body mass. Bivalves are mainly benthic dwellers and show no conspicuous colorations on the body surface, although some show dull color patterns on the shell.

The coloration of giant clams is neither species specific nor genus specific. The coloration differs from shell to shell, so that it doesn’t seem to be under genetic control. Since most of symbiotic bivalves, such as heart shells and giant clams, show brilliant colors on their mantles which are usually extended over the shell openings to get full solar light for photosynthesis for symbiotic algae. The brilliant coloration of the clam seems to filter strong solar radiation through colorful iridophores and protect the symbiotic algae against hazardous radiation.

Iridoscent coloration appears on various animals showing bluish or greenish hue on their body surfaces. Most animals usually lack genuine pigments of blue or green. In these animals, iridoscent color is produced by a special cell that is called iridophore, in which fine light reflecting platelets are arranged so as to split and reflect a certain spectrum of the incident light. In vertebrates, reflecting platelets are composed of crystallized purines, such as guanine or uric acid (2, 3), while reflecting devices in invertebrates are consisted of various materials (4, 6). In mollusks, some of squids, octopi and nudibranchs have iridophores in the skin that split and reflect the light, and exhibit conspicuous colors on their body surfaces. Iridoscent colorations depend on optical nature of platelets through which incoming ray travels. Theoretically a certain spectrum is reflected back to the same direction by multilayered thin films with the same optical pass (that is a value made by thickness of the film multiplied by the optical density of the film). When these reflecting platelets are aligned in a row in uniform interval, it reflects back a strong monochromatic color from the body surface (6).

**RESULTS**

Iridophores in the mantle were distributed in clusters among muscle cells, and occupied roughly the area to cover the outer layer of digestive diverticula where symbiotic algae, zooxanthellae, were colonized (Fig. 1). The iridophore was spherical in shape with an oval nucleus in the peripheral area of the cell (Fig. 2). The rest of cytoplasm was fully occupied with rows of reflecting platelets (Fig. 3). The platelet was electron dense and rectangular in shape having thickness of 80nm to 150nm. Each platelet was enveloped with a membrane of 7nm thickness (Fig. 4). Reflecting platelets were aligned in a definite interval with an intervening flat vacuole in between (Fig. 5). Although the thickness of the platelet and intervening distance between platelets were uniform within each cell, they differed slightly from cell to cell. This difference among cells makes color differences of the pigment cells that ranged red to purple. These differences might cause color difference among cells. The intervening vacuoles contained no substantial matter and often fused with plasma membrane allowing the inside of the vacuole open to the
extracellular space. In the matured iridophores, only few organelles, such as mitochondria, endoplasmic reticula and ribosomal granules were observed confined area around the nucleus.

In iridoblasts which were in earlier developmental stages, many endoplasmic reticula and Golgi complexes were observed around the nucleus. Numerous vacuoles and vesicles of various shapes and sizes were also observed in this area (Fig. 6). Developing platelets were detected in the vicinity of this area. The developing platelets were smaller in size than the matured ones and often lacked associating intervening vacuoles along them. In this area of the iridoblasts, various forms of vacuoles that would represent developing stages of the platelet were observed. In the earliest stage, the vacuole appeared as a distended cistern of the endoplasmic reticulum in which Golgi vesicles were incorporated to make a multivesicular body. The multivesicular body became condensed to make a dense spherical body as the infusion of the vesicles and ribosomal granules proceeded. The dense body was bounded with a membrane in this stage. As the dense bodies were flattened to form rectangle platelets, they were aligned along flat vacuoles side by side to make a row of reflecting platelets.
Fig. 1. Micrograph of a portion of mantle tissue of giant clam, *Tridacna crocea*. Just under the surface (left), zooxanthellae (dense circular bodies) and iridophores (grey bodies) are observed. Zooxanthellae are inhabited deeper potion of the tissue (right side) and iridophores are distributed more periphery of the tissue.

Fig. 2. A micrograph of pigment layer of mantle tissue of giant clam. Cluster of iridophores are clustered among muscle cells. The pigment cell is spherical and has a nucleus in the periphery. Most of the cytoplasm is occupied with reflecting platelets that appear as dense rods in transverse section. Platelets are arranged in rows of twenty to thirty aligned parallel one another.

Fig. 3. An iridophore showing a transverse profile. The cell is filled with reflecting platelets. Platelets are arranged in parallel and kept in uniform intervals by intervening flat vacuoles. Few organelles are seen around the nucleus.

Fig. 4. A reflecting platelet sectioned along horizontal plane. The dense reflecting body mass of the platelet is enveloped by a membrane. Crystalline structure with fine lattice of 3nm is visible along the longitudinal axis at thinner area (left side of the platelet).
Fig. 5. Platelets sectioned transversely aligned under the plasma membrane. A long flat vacuole is seen between platelets. A flat vacuole is seen fusing to the plasma membrane so that vacuolar cistern is opened to the external space. The platelet mass is enveloped with a membrane which is slightly thinner than the intervening vacuolar membrane. Fine crystalline structure is visible in each platelet.

Fig. 6. Platelet forming area of a developing iridophore. Diverse forms of vacuoles are seen around the Golgi complex. Golgi vesicles are seen associated with earlier stages of the vacuoles. Some vacuoles show the same internal density with the reflecting platelet. This figure is reproduced from the Ref. No. 9 by the permission of Zoological Society of Japan.

Fig. 7. Effect of iridophore on hatching rate of fish eggs under UV irradiation. Under normal fluorescent light (control), almost all eggs are brought to hatch, while it is severely deteriorated under the black light. Guanine solution over the eggs restored the hatching rate to the control.

Fig. 8. When symbiotic zooxanthellae are depleted (left), iridescent color of the mantle (right) is disappeared. The clam was died few days after the elimination of the algae.
DISCUSSION

The fundamental structure of giant clam iridophores is similar to those of Cephalopods(7, 8) and Vertebrates(3, 9). The cytoplasm of the cell is tightly packed with reflecting platelets that are aligned in rows and form multiple reflecting planes at each interface with the cytoplasmic space. The space was measured about 70nm, that seems to be small value to make an effective interference. However, there are no cytoplasmic substances observed in the cell except reflecting platelets, the cytoplasm seems to be shrunk during the dehydration process. The reflecting platelets are similar in shape and thickness but differ in size. Each platelet is rectangle in shape and has thickness of 80nm to 150nm, which may make purple to red interference color with the wider interspaces. The platelet is enveloped with a single limiting membrane. The limiting membrane seems to be similar to the plasma membrane or vacuolar membrane in structure and dimension. This suggests the platelets are formed from vacuoles. This can also be confirmed by the fact that various types of vacuoles are observed in the platelet forming area (Fig. 6). The chemical nature of reflecting platelet is yet to be identified. However, since Golgi vesicles and ribosomal granules are seen fusing to the developing platelet during the platelet condensation, proteins and nucleic substances seem to be the main component of the platelet. In siphonal mantle of the giant clam, some UV absorbing substances such as mycosporine-like amino acids are detected (10). This will suggest a clue to the nature of reflecting platelets. If chemical property of the platelet is of proteinous or of nucleic acid, it will suggests that the iridophores have a significant role other than color emission on the photosynthesis of symbiotic zooxanthellae by filtering hazardous radiation out from the incoming solar ray. Vertebrate iridophores which are constructed as the same designation with the clam or iridophores show UV filtering role as well as iridescent color production (Fig. 7).

Although color of the mantle is essentially produced by the iridophores, the characteristic coloration is enhanced by the symbiotic algae. The incoming light in the mantle is diffused by tissue structure but it is absorbed by brownish pigment of the zooxanthellae, just like melanophores in cephalopod skin that absorb diffused light and enhance the reflecting spectra by iridophores. When zooxanthellae were evacuated from the mantle tissue by warming up the culturing sea water, the brilliant coloration was disappeared and the tissue remains white due to the diffusion and scattering of the incoming light (Fig. 8). After evacuation of zooxanthellae the clam could not survive.

REFERENCES


2 Fox, H. M. and G. Vevers. The nature of animal colours. Sidgwick and Jackson Ltd (1960),

3 Kawaguti, S. Electron microscopy on iridophores in the scale of the blue wrasse. Proc. Japan Acad. (1965), 41: 610-613


ABSTRACT

UV radiation poses several problems to organisms in tropical marine environments, because of the shorter light path for sunlight and the clearness of the seawater. Since the discovery of UV-absorbing substances in organisms in the Great Barrier Reef, it has been thought that many coral reef invertebrates hosting symbiotic micro-algae might protect themselves by having UV-absorbing substances, mycosporine-like amino acids (MAAs) as sunscreen. However, MAAs in the tissues have not been visualized yet. Some didemnid ascidians have prokaryotic symbiotic algae, *Prochloron* sp. in their colonies. Their colony is covered with a gelatinous integument, tunic, which is transparent to visible light but is known to contain MAAs. In cross-sections of unfixed tunic of colonial symbiotic ascidians, *Lissoclinum patella* and *Diplosoma* sp., by UV-light microscopy, we observed a layer of highly vacuolated cells strongly absorb UV-light.
AN ACCOUNT OF THE 1976 SURVEY ON PALAU CORAL REEFS

Kiyoshi Yamazato
Meio University, 1220-1, Bimata, Nago, Okinawa, 905-8585 Japan
Email: kyamazato@msi.biglobe.ne.jp

ABSTRACT

This is a brief account of what was done in a coral reef survey in Palau in 1976. This survey was organized and led by late Dr. Masuoki Horikoshi, then professor of the University of Tokyo’s Ocean Research Institute. This survey was conducted during 31 days from July 31, 1976 and the survey team was composed of 9 members including myself. The results of this survey was planned to be published as 25 papers but have not been done so far. If we could present all the results of this survey in this conference, it would have been most appropriate. But this is not still possible. Instead, I would like to describe what kind of field research was conducted in the survey. The survey was more or less concentrated on the lagoon fringing reefs around the islands near Koror Island. The survey of the outer reefs was planned originally, but was not possible because of the weather condition. In addition to the faunal survey on corals and other reef organisms, community structure of corals, mollusks, sea grass beds, algae, sandy bottom, plankton and mangroves were studied. The survey on the poisonous organisms was also carried out. Outline of these studies will be introduced, together with some descriptions on a few subjects the author himself was personally involved.

INTRODUCTION

A group of scientists lead by late Dr. Masuoki Horikoshi, then professor of ecology at the Ocean Research Institute of the University of Tokyo conducted an ecological survey of Palau during July 31 to August 31, 1976. The survey was titled as Ecological Research on the Coral Reef Area Ecosystem in Palau, and supported financially by the Japanese Ministry of Education, Science, Culture and Sports. This is a brief account of this survey. As is shown below, this survey is wide in scope and involves many scientists belonging to different institutions. Although the result of this survey was planned to be published in 25 titles, but has never been accomplished. It could be accomplished in future, but as a member of this survey and a person who has been scheduled to be a co-author of the general account of the survey, I thought this conference is providing a good occasion to introduce this survey. Because it has been planned to make a comprehensive report, what I can do here is to make a brief account on the scope of the survey and make more or less detailed report on a subject which I have personally studied.

PURPOSE OF SURVEY

Late Professor Masuoki Horikoshi, the leader of this survey described the purpose of this survey as follows. “For the proper understanding of the ecosystem in the “coral reef area”, it is necessary to take up the lagoon, reef-flat, sea-grass meadow and mangrove as well as the reef itself, as the component parts of this ecosystem. It is also necessary to regard such types of habitats as component parts arranged serially in this ecosystem which extends from the margin of outer reef that is exposed to the open ocean to the mangrove, that is the transition zone to the terrestrial ecosystem. From this reason, it is required to make cooperative studies by scientists of different specialities, not only the reef biology but also planktology and benthology, in the same place at the same time.
At present, we are making such a concentrated cooperative researches in a small bay (Kabira Bay) on Ishigaki Island in the southernmost part of Okinawa Prefecture (rather near Taiwan). In order to make a reliable comparison to this, it is desirable to make similar researches and surveys in the truly tropical environment. Palau is rather similar in physiographical and topographical sense to Ishigaki Island, having a larger island among the Micronesian coral islands, and this place also gives so much scientific benefits for such a research like this, since there is a large accumulation of biological data made by Japanese and American marine scientists before and after the World War II.

In Palau, both quantitative and qualitative sampling of reef animals and plants, endobiotic benthos in the sediment bottom, sea-grass and plankton, will be made. The distributions of animals and plants together with that of biotic-community-types will be studied in relation to the physiography, submarine topography, and physical environmental factors, in order to know the structure of the "coral-reef-area ecosystem".

MEMBERS AND THEIR RESEARCH SUBJECTS

The members of the survey and their individual subjects were as follows. The institution of each member is that of the time when the survey was made.

Dr. Masuoki Horikoshi, University of Tokyo, Ocean Research Institute, Chief Scientist and Biology of Mollusca
Dr. Yusho Aruga, Tokyo University of Fisheries, Plankton and Physicochemical factors
Dr. Hisao Kamiya, University of Tokyo, Faculty of Fisheries, Ecology and biochemistry of poisonous animals
Dr. Hiroshi Mukai, University of Tokyo, Ocean Research Institute, Benthos and Sea grass
Dr. Moritaka Nishihira, University of the Ryukyus, College of Science and Technology, Benthic ecology
Dr. Suguru Ohta, University of Tokyo, Ocean Research Institute, Echinoderms and Underwater photographic survey
Mr. Eiji Tsuchida, University of Tokyo, Ocean Research Institute, Ecological distribution of Mollusca
Dr. Kiyoshi Yamazato, University of the Ryukyus, College of Science and Technology, Corals
Mr. Minoru Yasumoto, University of the Ryukyus, College of Science and Technology, Technical Support

SURVEY SCHEDULE

The survey was conducted according to the following schedule. The major survey stations are shown by figures in the parentheses, which are also indicated in Figure 1. The intertidal survey at Arakabesan Island and the visit to Peleliu Island were conducted by a small group. The visit to Babeldaob Island
was an orientation visit. The places where the underwater quadrat surveys were made along transect lines were indicated by the figures in parentheses, and marked on the map of Figure 1.

July 30        Arrival at Palau
July 31        Preliminary survey in and around Iwayama Bay and a brief observation at Geruherugairu Passage (3) and Oguratageru Passage (1)
August 1       Brief survey at the intertidal zone of the northern shore of Koror Island
August 3       Field study at Geruherugairu Passage near Tr. XI of Dr. Abe, 1937 (3) (Abe, 1937)
August 4, 5, 6 Field Survey at Rebogoru Passage near Tr. Vb of Dr. Abe (4) (Abe, 1937)
August 7       Field Survey at Geruherugairu Passage (3)
August 8, 9, 12 Intertidal zone of Arakabesan Island
August 10, 11  Field survey at the western barrier reef (7)
August 13      Field survey at a patch reef (6), south of Urukutaburu Island
August 14      Field survey at Megane Rock reef (5), east to Urukutaburu Island
August 18 to 21, 24  Field survey at Tsukikage-Tan cove (2)
August 23      Garamadu Bay, Babeldoaob Island
August 27      Peleliu Island
September 1    Left Palau for Guam and Japan
Figure 1. A map of the southern Palau Islands, showing stations of the 1976 survey. Inset shows an enlarged version of Arumizu Bay, Iwayama Bay, to show the location of Tsukikage-Tan cove. Black circles with numbers indicate the survey stations: 1: Ogurutageru Passage, 2: Tsukikage-tan Cove, 3: Geruherugairu Passage, 4: Rebugoru Passage, 5: Megane Rock, 6: A patch reef south of Urukutaburu Island, 7: Western barrier reef. The map was prepared based on Falkner, 1974 and Abe et al., 1937.
OUTLINE OF SURVEY

At most survey points, transect lines were extended from tidal level downwards and observations on the benthic organisms and measurements on topography, and physical and chemical factors were made. Along each transect lines, several 1 m² quadrats were located and semi quantitative measurements and counting on benthos and physico-chemical factors were made. Representatives of some organisms were collected for later taxonomic analyses. In addition, plankton and fish collection were made for later taxonomic and toxicological studies. A rather detailed survey was conducted at Tsukikage-tan cove of Iwayama Bay. In this report the results of this small cove was described in some detail and those on the other stations will be reported elsewhere.

SOME COLLECTED DATA AND TAXONOMIC RESULTS

During the survey, we collected the following data and biological samples. When there are duplicate samples, half of the samples were given to Micronesian Mariculture Demonstration Center, and the remaining portion are brought back to Japan for further study. The coral specimens are deposited at the University Museum of the University of the Ryukyus.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transects</td>
<td>13</td>
</tr>
<tr>
<td>Quadrats</td>
<td>30</td>
</tr>
<tr>
<td>Color slides</td>
<td>4,200</td>
</tr>
<tr>
<td>Black and white photos</td>
<td>500</td>
</tr>
<tr>
<td>Stereoscopic photos</td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TAXONOMIC GROUP</th>
<th>NO. OF SPECIES</th>
<th>NO.OF SAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reef building corals</td>
<td>230 (55 genera)</td>
<td>1,350</td>
</tr>
<tr>
<td>Shallow water shells</td>
<td>523</td>
<td>3,000</td>
</tr>
<tr>
<td>Subtidal shells</td>
<td>191</td>
<td>2,000</td>
</tr>
<tr>
<td>Starfish</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>Sea cucumber</td>
<td>35</td>
<td>200</td>
</tr>
<tr>
<td>Sea urchin</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Crustacea</td>
<td>15</td>
<td>100</td>
</tr>
<tr>
<td>Other invertebrates</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>Algae</td>
<td>25</td>
<td>120</td>
</tr>
<tr>
<td>Sea grass</td>
<td>6</td>
<td>10</td>
</tr>
</tbody>
</table>
DETAILED STUDY OF TSUKIKAGE-TAN COVE

Tsukikage-Tan is a small cove situated at the southern shore of Arumizu Bay, the inner most part of Iwayama Bay, and opens toward north (Figure 1 and 2). Tsukikage-Tan is a Japanese name, and may be translated as a moon reflecting pond. It is surrounded by steep limestone hills up to 150 meters high which are covered with dense woods. Its dimensions are about 120 meters long and 100 meters wide. It is connected with the out side, Arumizu Bay through a narrow and shallow passage, about 50 meters wide. The limestone wall around the cove is deeply notched (Figure 3, C and D). The notches are excavated up to 4 meters and the trees above notches hang over the water surface as extensive as about 10 meters wide. This broad sunshade cuts sun light so extensively that the inside the notch is very dark even during the day time.

The location of a small cove surrounded by limestone hills which are the southern extension of Koror Island (Figure 1). The cove looks like a small lake with maximum depth of about 20 meters (Figure 2). Around this cove 10 transect lines were located. Transect O is placed out side the cove, and the other 9 transects are located inside the cove, and named A, B, C, D, - -, I clockwise. Transect A was located at the right side of the entrance, Transect E at the innermost side, and Transect I at the left side of the entrance. The cove is surrounded by high limestone hills covered with tall trees.

Because the shallowest margins of the cove is notched deep and under the wide and low roof of the notches and stretching tree branches, it is the most dark even at the surface in the margins. As a result, the light intensity diminishes both ways, vertically toward the bottom and horizontally toward the water margin (5). The surface light intensity is the strongest and decreases toward the periphery and the lowest under the notches.
The vertical distribution of light shows the highest intensity at the surface of the center of the cove, and decreases towards the bottom. However, the bottom light intensity is lower both at the center as well as at the periphery under the notches, and increases toward the intermediate bottom between the periphery and the center of the cove, the area which is intermediate depth. In other word the bottom light intensity is the lowest at the intermediate depth. This characterizes the distribution of light of Tsukikage Tan, which is quite different from other aquatic environments.

This pattern of light distribution is well reflected in the distribution of coral species number. The least number of species is found at the shallowest area of the periphery of the cove which has the lowest light intensity under the shades of the notches. The same trend is also observed in the coverage and number of colonies. The same trend is also expected in the size of corals, but unfortunately, the size of coral colonies was not measured in the field. But this can be roughly estimated by the quotient of the coverage divided by the number of colony (Table 1).
Figure 3. Photographs inside and outside of Tsukikage-tan cove, Iwayama Bay, Palau.
A: Disk-shaped colonies of *Porites (Synarea) iwayamaensis* Eguchi 10 meters deep at Transect O, outside the cove.  
B: A cone-shaped colony of *P. (S.) iwayamaensis* Eguchi at the surface of Transect O.  
C: Obliquely oriented colonies of *Leptoseris solida* (Quelch) 3 meters deep at Transect D.  
D: Crowded colonies of different species of corals 14 meters deep at Transect D, note the white borders of colonies indicating damages caused by competition or the buffer zones to avoid damages of competition.  
E: Late professor M. Horikoshi (right) examining land snails at Transect E,  
F: A deep notch covered with tree branches at Transect C.
Table 1. Distribution of corals as affected by light intensity at Tsukikage-tan Cove, Palau. The data are compiled by M. Nishihira.

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>0.5</th>
<th>1</th>
<th>10</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (lux)</td>
<td>768</td>
<td>14</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>No. of Species</td>
<td>13.4</td>
<td>14</td>
<td>63.5</td>
<td>11</td>
</tr>
<tr>
<td>Coverage</td>
<td>36</td>
<td>41</td>
<td>31</td>
<td>24</td>
</tr>
<tr>
<td>No. of Colony</td>
<td>0.37</td>
<td>1.56</td>
<td>2.05</td>
<td>0.64</td>
</tr>
<tr>
<td>Cov./Colony</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>0.8</th>
<th>2</th>
<th>10</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (lux)</td>
<td>374</td>
<td>1,088</td>
<td>2,550</td>
<td>2,448</td>
</tr>
<tr>
<td>No. of Species</td>
<td>10</td>
<td>20</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Coverage</td>
<td>26.8</td>
<td>74.1</td>
<td>49.8</td>
<td>30.6</td>
</tr>
<tr>
<td>No. of Colony</td>
<td>30</td>
<td>59</td>
<td>86</td>
<td>67</td>
</tr>
<tr>
<td>Cov./Colony</td>
<td>0.89</td>
<td>1.26</td>
<td>0.58</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>0.8</th>
<th>2 to 3</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (lux)</td>
<td>323</td>
<td>2,040</td>
<td>2,890</td>
<td>1,734</td>
</tr>
<tr>
<td>No. of Species</td>
<td>13</td>
<td>17</td>
<td>22</td>
<td>11</td>
</tr>
<tr>
<td>Coverage</td>
<td>39.3</td>
<td>53.2</td>
<td>40.1</td>
<td>33.4</td>
</tr>
<tr>
<td>No. of Colony</td>
<td>34</td>
<td>55</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Cov./Colony</td>
<td>1.15</td>
<td>0.97</td>
<td>0.53</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>1.2</th>
<th>2 to 3</th>
<th>10</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light (lux)</td>
<td>476</td>
<td>1,190</td>
<td>847</td>
<td></td>
</tr>
<tr>
<td>No. of Species</td>
<td>11</td>
<td>11</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>Coverage</td>
<td>16.5</td>
<td>30.2</td>
<td>8.4</td>
<td></td>
</tr>
<tr>
<td>No. of Colony</td>
<td>25</td>
<td>26</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Cov./Colony</td>
<td>0.67</td>
<td>1.16</td>
<td>0.16</td>
<td></td>
</tr>
</tbody>
</table>

Some other effects of light on corals are illustrated in the shape of the coral, *Porites* (*Synarae*) *iwayamaensis* Eguchi (=rus (Forskål)) from cone shape to flat disk shape as the depth becomes deeper, from the surface to the depth of 10 meters (Figure 3, A and B). Another example is shown in the posture of coral colonies under the shades of notches. Here are the colonies of *Leptastrea solida* (Quelch) with their disk-shaped fronds kept oblique towards the center of the cove, instead of horizontal posture under the normal environments, probably reflecting the oblique direction of light inside the cove (Figure 3, C). It is quite a different posture which can be seen in the horizontal posture of *P. (S.) iwayamaensis* outside the bay (Figure 3, A).
Table 2. Relationship between aggression hierarchy and frequency of occurrence
Among the scleractinian corals of Tsukikage-Tan, Iwayama Bay, Palau.

<table>
<thead>
<tr>
<th>Hierarchy</th>
<th>Coral species</th>
<th>Frequency of occurrence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Surface</td>
</tr>
<tr>
<td>I</td>
<td>Pavona olivacea</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Echinopora lamellose</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>Leptastrea purpurea</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Pavina purpurea</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Pavona minuta</td>
<td>0</td>
</tr>
<tr>
<td>III</td>
<td>Leptoseris solida</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Cyphastrea microphthalmal</td>
<td>75</td>
</tr>
<tr>
<td></td>
<td>Goniastrea pectinata</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Pavites lichem</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Pavites australiensse</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Pavones contigua</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pavones sp. 1</td>
<td>0</td>
</tr>
<tr>
<td>IV</td>
<td>Pavina pallida</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>Pavites hallopora</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Stylocomeella armata</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>Pavites lutea</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Pavites (S) horizontalata</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Cyphastrea seralia</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pavites andrewsi</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Pavites complanata</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Pectina laricostata</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Pavones demussata</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Lobophyllia hemprichii</td>
<td>0</td>
</tr>
</tbody>
</table>

Another interesting aspect of coral life in this cove is the intense competition for the space of the bottom among the colonies. At the bottom corals are so much crowded that they can not avoid touching with each other. But interestingly, they seem not necessarily fight with each other, but coexist somehow by making a buffer zone among each other (Figure 3, D). However, there are many cases of fighting each other. Table 2 illustrates some examples of hierarchical relationships among different species. In this table, corals are grouped into 4 groups, according to their inter-specific aggressiveness, with the top group being most aggressive. More aggressive species over-grows less aggressive ones at the contact points. When equal in aggressiveness, corals avoid aggression by some means, such as making buffer zone without tissue, making calcareous walls or making buffer zones at the contact points.

Frequency of occurrence is estimated by the number of quadrats containing a particular species of corals at each level, surface (less than 1 meter), intermediate (2 to 10 meters) and bottom (15 to 20 meters). Three to four quadrats were placed along each of 4 transects, O, C, D, and E, at three levels, each. The data of Table 2 shows that the most aggressive corals do no necessarily more abundant. This may be one of examples to show that aggression is not only factor to determine dominance in inter-specific interaction. It is interesting to note that Echinopora lamellose, (Esper) one of the most aggressive species is rather one of the least abundant coral. The reason for this is not known, but one possibility is that this species may have a weak power of dispersion and hence to tend to be crowded in a particular habitats. In Tsukikage-Tan cove, big colonies of this species were found in Transects F and G.
This paper is only to introduce what kind of study was made in this survey. As was described above, the survey covered various fields. The results of other field of study will be published elsewhere. Although, this report describe a little detailed aspects of the survey on Tsukikage-Tan, but there are many more aspects to be described, including the faunistic analysis of corals and other animals. These may be also reported elsewhere.

ACKNOWLEDGMENT

This survey was planned and organized by late Professor Masuoki Horikoshi. I would like to take this opportunity to thank him for giving me a chance to join this survey. I also like to thank all the members of this survey team, who cooperated in making this survey. The data presented here were taken in cooperation of all the members. Taxonomic and ecological studies on corals were particularly conducted in collaboration with Dr. Moritaka Nishihira. My special thanks goes to him.

REFERENCE


Direct and indirect effects of sedimentation on coastal reef communities

Katharina Fabricius  
Australian Institute of Marine Science  
PMB 3, Townsville M.C., Queensland 4810, Australia  
Email: k.fabricius@aims.gov.au

ABSTRACT

The amount of sediment discharged into the Great Barrier Reef has increased several-fold since pre-European settlement. However, the amount of sediment added each year through river plumes is comparatively small compared with the sediment that is on the sea floor surrounding coral reefs. For this reason, the potential effects of increasing sediment runoff into the Great Barrier Reef are still highly controversial. The question remains whether newly imported sediment, which is the main carrier for nutrients and some pollutants, has a different effect on reef organisms than resuspended old and reworked sea floor sediment. To address this question, we compared the photophysiological stress in corals exposed to varying amounts and different types of sediments (varying grain sizes, and from four origins: river and offshore sediments from both an agricultural and a sparsely-inhabited region in Queensland). We also examine the evidence of changes in ecological functions in coastal coral reef communities due to terrestrial runoff. Lastly, we propose a new ecological approach to assess potential environmental impacts in complex ecological communities, and introduce some of the management actions recently proposed by the Australian Government to halt and potentially reverse the decline in water quality in inshore reefs of the central Great Barrier Reef.
Effects of suspended and deposited red-soil particles on larval settlement of corals

Saki Harii* and Kazuo Nadaoka
Graduate School of Information Science and Engineering, Tokyo Institute of Technology
Ookayama, Meguro-ku, Tokyo 152-8552, Japan
Tel +81-3-5734-3486   Fax +81-3-5734-2650  * Email: harii@wv.mei.titech.ac.jp

ABSTRACT

Larval dispersal and recruitment of hermatypic corals regulate the population dynamics of coral reefs. Actual recruitment process may be influenced by various anthropogenic environmental stresses, causing deterioration of coral reef ecosystems. Among these, in Ryukyu Islands, Japan, sedimentation onto coral reefs resulting from red-soil erosion in adjacent watersheds is one of the major environmental stresses. Although sedimentation may affect larval settlement and recruitment, little is quantitatively known about the effect of suspended and deposited particles of red soil on the settlement of coral larvae. In the present study, the effect has been investigated by laboratory experiments for two different reef coral species.

The experiments were conducted at Akajima Marine Science Laboratory and Ishigaki Tropical Station, Seikai National Fisheries Research Institute, in Ryukyu Islands, Japan in June and July 2002 and 2003. Acropora tenuis and Heliopora coerulea were chosen as the study species. Red soil was collected from a terrestrial area in Ishigaki Island, filtered with a sieve of 75 μm mesh and freshwater, and dried. The settlement rate was measured in various concentrations of suspended red-soil particles, i.e., 0 (control), 10, 50, 100, and 200 mg/L. The settlement rate was observed also in different amount of deposited red-soil sediments, i.e., 0 (control), 0.9mg/cm², 1.9mg/cm², and 3.8 mg/cm². In both the series of experiments, planulae were added in the container, where the settlement plates were put horizontally and/or vertically to examine the effect of the direction of the plates. The number of planulae settled on the plates was counted 1 and 2 days after the beginning of the experiments. In the condition of red-soil suspension, about 60% planulae settled on the plate in 0 and 10mg/L conditions for A. tenuis and H. coerulea. The appreciable decrease in the settlement rate was observed at the concentration of 50mg/L or more and at 200mg/L the settlement rate was decreased to 20% and 33% for these two species, respectively. In the sediment deposition circumstance, the settled planulae decreased with the increase in the amount of sediment deposition especially on the top of the horizontal plates. At 3.8 mg/cm², the settlement rates were 0% for A. tenuis and 2% for H. coerulea. In contrast, higher number of settled planulae were observed on the under surface of the horizontal and vertical plates, indicating that planulae selected settlement plate surface with less amount of the sediments. Swimming behavior of planulae in the suspended particle conditions was not different from that in the control condition, but planulae spat out mucus substance. In the condition with deposited sediments, tracks with mucus of crawled planulae were observed on the plates. This study demonstrates that suspended and deposited red-soil sediments appreciably inhibit settlement of planulae. In addition, planulae may spend their energy due to producing mucus substance under both suspended and deposited sediment conditions.
Effects of land use change on coastal coral reefs, Palau, Micronesia

Steven Victor1*, Yimnang Golbuu1, Eric Wolanski2 and Robert Richmond3

1 Palau International Coral Reef Center, P.O. Box 7086, Koror, Palau 96940, Micronesia.
*E-mail: svictor@picrc.org
2 Australian Institute of Marine Science, PMB No. 3, Townsville MC, Qld. 4810, Australia.
3 Marine Laboratory, University of Guam, UOG Station, Mangilao, Guam 96923 USA

ABSTRACT

The Ngerikiil watershed catchment has experienced major land use change resulting in increased sedimentation while Ngerdorch catchment is still relatively pristine. A comparative study was undertaken in the mangrove fringe-estuaries downstream in each watershed catchment to determine the level of sedimentation and the role of mangroves in mediating sedimentation onto coral reefs. The sediment yield is 10-19 times higher in the Ngerikiil River catchment compared to the Ngerdorch River catchment.

The mangroves comprised 3.8% of each catchment area, and in both systems they trapped about 30% of the riverine sediment. The mangroves are important buffer protecting coastal coral reefs from excessive sedimentation. However, the ability of the mangroves to protect coastal coral reefs is greatly influenced by the degree of land use management in the watershed catchment.

INTRODUCTION

Poor land use practices in watershed catchment has resulted in increased soil erosion on many tropical islands. Increased soil erosion is threatening estuaries and fringing coral reefs (Meade, 1996; Edinger et al., 1998; Fortes, 2001; Dubinsky and Stumbler, 1996; McCook et al., 2001; Wolanski and Spagnol, 2000; Wolanski et al., 2003). Golbuu et al. 2003 reported that mud resulting from soil erosion in Ngerikiil watershed catchment has lead to die-off of corals in Airai Bay in Babeldaob Island, Palau, Micronesia (7°22’S, 134°34’E; Figure 1). There are no pre-development data on soil erosion rates in the area to help understand the increase in sediment yield during development. However, local residents attribute the recent increased erosion in the catchment, the reported rapid siltation of the estuary, and the die-off of coral reefs in Airai Bay to development activities in the catchment.

The Ngerdorch River is a 39 km² mountainous catchment and adjacent to the Ngerikiil River catchment, which is about 26 km² (Figure 1). These two catchments have a similar geology, topography and rainfall (USDI, 1997), as well as an identical tidal range. Both rivers flow into coral-fringed lagoons with a mangrove swamp that comprises 3.8% of the catchment area that fringes the whole length of the estuary to the tidal excursion limit.

In 2000 the ‘Babeldaob Compact Road’ (a 52 mile road construction around Babeldaob) and the ‘Capital Relocation’ (a new capital building in Melekeok) projects were initiated. A portion of the Compact road goes through Ngerikiil and Ngerdorch catchments and the new Capitol Building is being constructed on the hillside of the Ngerdorch catchment. These developments will lead to large-scale land clearing and soil erosion in the near future. In 2002, the Ngerdorch River catchment was still largely pristine, being largely forested with only three small farms in the catchment while Ngerikill catchment has experienced increased housing and farming developments.
Figure 1. Map of Palau showing location of Ngerikiil and Ngerdorch watershed (a) and location of sediment traps in Ngerdorch estuary (b) and location of moored instruments in Airai Bay (c)
To assess the effect of land use change on soil erosion, we undertook a field study to quantify the riverine sediment load, and role of mangroves in mediating siltation onto coral reefs. By comparing the Ngerikiil and Ngerdorch estuaries, it may be possible to quantify the effect of land use change on soil erosion and the trapping efficiency of mangroves.

METHODS

Four oceanographic moorings were deployed along the along-channel transect at stations S0 to S3 in Airai Bay in February to June (Golbuu et al, 2003) and in Ngerdorch estuary (Figure 1) in September and October 2002. Salinity, temperature and suspended sediment concentration (SSC) were measured at stations 1 (at 1m above the bottom in 4 m depth) and 3 (at 2 m below the surface in 6 m depth), using self-logging Analite nephelometers, Dataflow salinometers, and a YSI self-logging CTD-cum nephelometer. The instruments were attached onto 1 meter long steel star pickets (rebar) driven into the substratum. The Analite nephelometers and YSI instrument were equipped with wipers that cleaned the sensor every 30 min and 10 min, respectively. The instruments logged data at 10 min intervals. The data were sampled at 0.5 s intervals and averaged over 1 min for all sensors except the YSI, which logged data continuously without averaging. The nephelometers were calibrated in-situ using water samples brought to the laboratory and filtered on 0.45 µm filters, which were dried at 60°C in a drying oven for 24 hours and weighted.

At station 2, in 6 m depth, the vertical profile at 0.5 m intervals of horizontal currents was measured at 5 min intervals using a bottom-mounted RDI Workhorse ADCP. In addition, the vertical profile of salinity, temperature and SSC were measured at stations S0 to S3 with a ship-born YSI CTD profiler-cum nephelometer. These measurements were carried out daily following a flood event in October 2002 for one week and occasionally for the duration of the study. Salinity is expressed in psu, which for our study sites is practically equivalent to ppt.

Single, bottom-mounted sediment traps, with a diameter of 5.08 cm, were mounted at the edge of the mangroves on the river bank between stations S0 and S3 and in the mangroves along a transect perpendicular to the river bank at 10, 20, and 30 m from station S1. The sediment traps were deployed on October 12, 2002 and recovered 120 days later.

The National Weather Service provided daily rainfall data at Koror, located about 12 km away. The rainfall data were used to correlate sedimentation rate and SSC values.

RESULTS

Semi-diurnal, meso-tides prevailed with a pronounced diurnal inequality, and a strong spring-neap cycle. The tidal range was about 2 m at spring tide and 1 m at neap tide in both estuaries. A salt wedge prevailed throughout the field study (Figure 2) and the isohalines were nearly horizontal in Ngerdorch estuary and was absent in Ngerikiil estuary. The brackish water plume lifted off the bottom between stations S0 and S1 in Ngerdorch estuary whereas in Ngerikiil estuary the freshwater and saltwater was well mixed.
Figure 2. Along-channel distribution of salinity and suspended sediment concentration (mg l$^{-1}$) in the Ngerdorch Estuary during October 17-18, 2002. Station locations are shown in Figure 1.
The suspended sediment concentration (SSC) contour lines were not parallel to the isohalines; instead they sloped upwards toward the Ngerdorch river mouth. A turbidity maximum zone existed near the lift-off point (Figure 2) in Ngerdorch estuary.

The salinity in the salt wedge at site S1 fluctuated as a result of both the tides and the rainfall (Figure 3). The largest values of salinity were found at high tide, and the lowest values at low tides. The SSC values in the salt wedge at site S1 also fluctuated at tidal frequency (Figure 3). They were the largest at high tide and following large rainfall.

During the field study, neither the freshwater plume nor the riverine fine sediment reached offshore waters (S3) in quantity (Figure 1), except once for about 20 minutes following a short river flood (Figure 3). The siltation rates in the mangroves were 0.0065, 0.0012, 0.0009 g cm\(^{-2}\) day\(^{-1}\) at 10, 20, and 30 m and were 0.014, 0.0065, 0.0052, 0.0039 g cm\(^{-2}\) day\(^{-1}\) at 10, 20, 30 and 50 m inside the mangroves from the banks of Ngerdorch and Ngerikiil estuary, respectively. Hence most of the suspended sediments are deposited within 50 m from the edge of the creek, in agreement with findings in other macro-tidal mangroves (Wolanski et al., 2001). The rates were based on two months of sediment monitoring. However, the longer term monitoring of sediment in Ngerdorch estuary shows an increase in daily rate (Table 1). This increase coincides with increased activity in the construction of the portion of the compact road that runs through the watershed catchment.

### Table 1. Daily sedimentation rate in Ngerdorch estuary as estimated by the sediment traps deployed in the estuary and the mangroves. Trap no. corresponds to the location at which the trap were located (Figure 1). Traps were deployed for a duration of two months.

<table>
<thead>
<tr>
<th>Trap No.</th>
<th>Jan.-march</th>
<th>March-May</th>
<th>May-July</th>
<th>July-October</th>
<th>Average Daily rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0044</td>
<td>0.0044</td>
<td>0.0327</td>
<td>0.0009</td>
<td>0.0106</td>
</tr>
<tr>
<td>2</td>
<td>0.1194</td>
<td>0.0979</td>
<td>0.0995</td>
<td>0.0165</td>
<td>0.0833</td>
</tr>
<tr>
<td>3</td>
<td>0.1581</td>
<td>0.2073</td>
<td>0.0890</td>
<td>0.1489</td>
<td>0.1508</td>
</tr>
<tr>
<td>4</td>
<td>0.0546</td>
<td>0.0125</td>
<td>0.1309</td>
<td>0.0805</td>
<td>0.0696</td>
</tr>
<tr>
<td>5</td>
<td>0.0953</td>
<td>0.0333</td>
<td>0.1519</td>
<td>0.1483</td>
<td>0.1072</td>
</tr>
<tr>
<td>6</td>
<td>0.0058</td>
<td>0.0122</td>
<td>0.0473</td>
<td>0.0185</td>
<td>0.0209</td>
</tr>
<tr>
<td>7</td>
<td>0.0010</td>
<td>0.0032</td>
<td>0.0421</td>
<td>0.0192</td>
<td>0.0164</td>
</tr>
<tr>
<td>8</td>
<td>0.0007</td>
<td>0.0021</td>
<td>0.0157</td>
<td>0.0192</td>
<td>0.0094</td>
</tr>
<tr>
<td>9</td>
<td>0.0225</td>
<td>0.1646</td>
<td>0.1205</td>
<td>0.1485</td>
<td>0.1140</td>
</tr>
<tr>
<td>10</td>
<td>0.1144</td>
<td>0.0437</td>
<td>0.0887</td>
<td>0.0886</td>
<td>0.0839</td>
</tr>
<tr>
<td>11</td>
<td>0.1820</td>
<td>0.2021</td>
<td>0.1938</td>
<td>0.1341</td>
<td>0.1780</td>
</tr>
<tr>
<td>12</td>
<td>0.1942</td>
<td>0.1083</td>
<td>0.0733</td>
<td>0.1073</td>
<td>0.1208</td>
</tr>
</tbody>
</table>
Figure 3: Time-series plot of daily rainfall, salinity and suspended sediment concentration (SSC) in the salt wedge at site 1 and near the surface at site 3, and velocity (>0 if seaward, <0 if landward) in the brackish water plume and in the salt wedge at site 2. Station locations are shown in Figure 1.
DISCUSSION

The observations and oceanographic data suggest a permanent freshwater inflow that formed a permanent salt wedge circulation in the Ngerdorch estuary. The salt wedge exists as a result of the small tidal currents and the large depth of the estuary. Because Ngerikiil estuary is very shallow as a result increased siltation, the estuary is not stratified but well mixed. The riverine fine sediment did not follow the freshwater flow in Ngerdorch estuary. Instead, the suspended sediment settled out of the brackish, surface plume and was re-entrained towards the head of the estuary by the baroclinic currents in the salt wedge. A turbidity maximum zone prevailed near the plume lift-off point. In Airai Bay, most of the riverine sediments settled out of suspension in the bay. Much of the sediments gets re-suspended and is imported into the estuary and the fringed mangroves during rising tide (Golbuu et al, 2003).

Occasional aerial observations (P. Collins, pers. comm.) suggest that the river plume in Ngerdorch estuary was deflected alongshore, and this may explain why in our observations the river plume generally did not reach offshore waters (S3). In Airai Bay, the river plume never reached offshore water also because the bay is semi-enclosed and the plume is restricted within the bay (Golbuu et al, 2003).

For the period of September-October 2002, the net fine sediment fluxes in the Ngerdorch River and out of the estuary were, respectively, $3.2 \text{ g s}^{-1} (\pm 1.915 \text{ g s}^{-1})$ and $2.3 \text{ g s}^{-1} (\pm 1.044 \text{ g s}^{-1})$ based on the calculated flow rate. This suggests that the mangroves may trap about $0.9 \text{ g s}^{-1}$, i.e. about 28% of the riverine fine sediment inflow. However, the sediment traps in the mangroves suggest a mean settling rate of $1.4 \text{ g s}^{-1}$, or about 44% of the riverine fine sediment flux. Interestingly, the mangroves trap a similar fraction of the fine sediment in the Ngerikiil Estuary, although the riverine fine sediment yield in this estuary is 10-19 times higher. In both the Ngerdorch and Ngerikiil estuaries the mangroves comprise about 3.8% of the catchment. This suggests that the sediment trapping efficiency of mangroves is a function of tidal dynamics in the mangrove wetlands, and not of riverine suspended sediment concentration.

The Ngerdorch estuary was still relatively pristine in 2002 compared to Ngerikiil estuary. The Ngerikiil watershed catchment has been heavily impacted by farming, road construction, and housing development. The impact is a direct result of the absence of land management, which has led to increased soil erosion to coastal areas. The results of the studies show that mangrove has a role in mediating siltation on coral reefs.

Thus mangroves play an important role in reducing coastal erosion (Mazda et al., 2001) and protecting fringing coral reefs from sedimentation. The Ngerikiil and Ngerdorch estuaries mangroves comprise 3.8% of the river catchment, they flood semi-diurnally, and they may trap up to 44% of the riverine fine sediment. As suggested by Golbuu et al. (2003) for the Ngerikiil River, this trapping efficiency, while helpful, is not sufficient to prevent degradation of coastal coral reefs from excessive sedimentation resulting from extensive land clearing and poor farming practices. Siltation of the Ngerdorch estuary and coral reef degradation in the lagoon waters is likely to occur if land clearing and poor farming practices are allowed to develop as they were the last few years in the Ngerikiil catchment. Therefore, an integrated watershed management approach is need for effective conservation of coastal coral reefs.

CONCLUSION

Because of the level of land use change in Ngerikiil watershed catchment, the sediment yield is 10-19 times higher than in Ngerdorch watershed. While Ngerdorch watershed catchment is still relatively
pristine, without proper land management, coral reef conservation and management effort may not be successful. No matter how much effort is put to conserving and protecting coastal coral reef habitats, if erosion is not controlled in the upland areas, the underlying impact of poor watershed management will be siltation of coral reefs. Siltation has a major negative impact on coral reefs by smothering corals and has the potential to affect recovery by limiting the ability of coral larvae to find suitable substrate for settlement. Therefore, in order to ensure the persistence of coastal coral reefs communities, management regimes must include human activities on land as well as the marine communities.

ACKNOWLEDGEMENT

The Palau International Coral Reef Center, the University of Guam, the Australian Institute of Marine Science and the US-EPA STAR program supported this study. The authors gratefully acknowledge the assistance and support of Jim Kloulechad, Arius Merep, Masao Udui, Sisinio Ngiramengloi and Kenjo Yamashiro.

REFERENCES


INTRODUCTION

This paper recognizes the fact some of the problems encountered in the coral reefs and marine environment of the Pacific are actually due to land-based activities. This message needs to be clearly brought to the attention of farmers and others who work the land – as well as to fishermen and others whose activities focus on coral reefs and the marine environment.

The paper discusses the Pacific environment and some relevant key issues. The paper goes on to discuss land-based activities that harm the coral reef environment – with some emphasis on agricultural activities and soil erosion; however, the impacts of other land-based activities are also discussed. Strategies for reducing the harmful effects of land-based activities are then discussed with reference to worldviews, various strategies, integrated approach and technical considerations.

The paper recognizes the Vetiver System as an appropriate mechanism for combating the effect of soil erosion and discusses this system to some detail – before ending with some conclusions and recommendations. However, the main message of this paper is that there is an urgent need to clarify the impacts of the various land-based activities on coral reefs and the marine environment, and to devise ways of minimizing or eliminating the negative effects of land-based activities.

THE PACIFIC ENVIRONMENT AND KEY ISSUES

There are a number of factors that contribute to the fact that the problems caused by land-based activities on the marine environment and coral reefs are critical in the Pacific islands. These factors include the small size of the majority of the islands which greatly reduces their buffering capacity and thereby greatly increases their vulnerability. In these small islands, the percentage of land area close to the sea is very high and is effectively 100% in most cases. As Power (2002) puts it, “…due to their size, most island states are entirely coastal entities”. This makes the impact of land-based activities on the marine environment and coral reefs more direct and immediate.

In the Pacific islands, there have been records of chemical dumping and poor regulation of land-based activities (Morrison and Brodie, 1985). In addition, there have been inadequate facilities to deal with waste (Morrison and Munro, 1999). These are related to the fact that most of the islands are economically weak and have given lower priority to the installation of the appropriate facilities required. Especially through the South Pacific Regional Environment Programme (SPREP), there have been a number of important initiatives and projects such as the introduction to the Pacific islands (via a Samoan project) of the Fukuoka Method of disposing and recycling rubbish, the International Waters Project to conserve and sustainably manage coastal and ocean water resources in the Pacific islands (SPREP, 2003:13-15), etc. However, the task at hand is a massive and complex one requiring a continual effort and collaboration of all stakeholders.
In the high volcanic and continental islands there is an additional problem due to erosion (Morrison, 1999). Some of the soils are quite erodible while some of the rains are highly erosive giving rise, in the absence of proper management, to high levels of soil loss and erosion. There is also the problem of rapidly increasing populations that is putting pressure on natural resources and the capacity of governments and communities to deal with problems relating to the unsustainable use of natural resources.

As population increases, more islanders have to share the resources obtainable from the sea and coral reefs. Increases in populations may result in a significant increase in pollutants entering the aquatic environment. For example, increasing populations have forced people on some islands to cultivate fragile soils on steep slopes, causing more soil erosion. As shown in Table 1, the population density in some island countries are as high as 300 people/km\(^2\) or more – with Nauru having the highest of 577 people/km\(^2\). However, in all Pacific islands, irrespective of population density, there are hotspots - pockets where people tend to concentrate, e.g., urban areas, and there are also areas that are vulnerable for one reason or another, e.g., areas with erodible soil or steepland.

Chemicals from land based activities can enter the aquatic environment via overland flow or via percolation downward through the soil. Percolation of chemicals in the Pacific is relatively easy for a variety of reasons. In the low coral islands, the soils are mostly sandy and hold only limited quantities of chemical ions – as sands, compared to clays, have extremely small surface areas per kg and practically no charge by which chemical species could be drawn to and held by the soil/sand particles. In the high volcanic and/or continental islands of the Pacific, the kind of clay present (oxyhydroxides) is highly weathered and also has very little charge compared to the clays (layer silicates) generally found in temperate countries. To make matters worse, these oxyhydroxide clays form good soil structures that allow easier percolation of rainwater (with any dissolved pollutant) to the underground water system.

There is also a dangerous trend in the Pacific islands with regard to the worldview of the local peoples. In pre-missionary days, people had an animistic worldview where nature including natural resources was greatly revered and some animals and plants (totems) were considered as gods and actually worshipped. In those days, when a temporary taboo was placed on fishing or harvesting of marine resources, there was no need to police or enforce the law as people greatly feared the consequences of displeasing the gods.

The missionaries came with the concept that there is only one God – the God of Love. Converts were released from their fear of the various gods they used to believe to control nature and thereby lose their respectful fear of nature itself. In Samoa for example, Meleisea (1987) referring to the Reverend John Williams’ diary reported how this missionary required new converts to eat their gods during village feasts. This represents a very drastic change in worldview that had serious environmental consequences.

Unfortunately, a more disastrous global influence is emerging – that of consumerism. This is of course part of a worldwide trend but will have a far more disastrous effect in the Pacific islands because of the small size of the islands, their economies and their capacity to cope with rapid economic changes. Crocombe (2001:231-2) referred to consumerism as the religion of commerce and one of the most barbaric ethical systems with the following four main commandments: (a) Yourself over others; (b) consumption over production; (c) waste over conservation; and (d) impulse gratification over long term consequences.

Below is a list of the key regional issues facing the Pacific islands with regard to sustainable development of their coastal and ocean environments as identified by Power (2002) who mentioned that these issues have been highlighted in a number of recent documents (Council of Regional Organizations
of the Pacific (CROP 2001a, 2001b and SPREP 2000):

- Implementation of management regimes and conventions relevant to the Pacific islands;
- Sustainable management of living resources (fisheries);
- Sustainable management of non-living resources (minerals);
- Pollution prevention and waste management;
- Marine biodiversity and natural resource conservation and management;
- Coastal degradation;
- Marine scientific research;
- Defense, surveillance, monitoring and enforcement;
- Sustainable tourism;
- Training, education, and public awareness;
- Shipping;
- Appropriate technology transfer;
- Climate change and sea-level rise;
- Natural and environmental disasters;
- Intellectual property rights/ ownership and access to genetic resources;
- Globalization; and
- Vulnerability.

### Table 1. Population, Land Area, Population Density and Sea Area of the Pacific Island Countries

<table>
<thead>
<tr>
<th>Country (or SUB-REGION)</th>
<th>Population (Est. mid-2003)</th>
<th>Land Area (km²)</th>
<th>Population Density (people/km²)</th>
<th>Sea Area (x 1,000 km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MELANESIA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fiji</td>
<td>7,337,900</td>
<td>539,732</td>
<td>14</td>
<td>8,170</td>
</tr>
<tr>
<td>New Caledonia</td>
<td>831,600</td>
<td>18,333</td>
<td>45</td>
<td>1,290</td>
</tr>
<tr>
<td>Papua New Guinea</td>
<td>235,200</td>
<td>18,576</td>
<td>13</td>
<td>1,740</td>
</tr>
<tr>
<td>Solomon Islands</td>
<td>5,617,000</td>
<td>462,243</td>
<td>12</td>
<td>3,120</td>
</tr>
<tr>
<td>Vanuatu</td>
<td>450,000</td>
<td>28,370</td>
<td>16</td>
<td>1,340</td>
</tr>
<tr>
<td>Micronesia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Federated States of Micronesia</td>
<td>525,000</td>
<td>3,214</td>
<td>163</td>
<td>11,649</td>
</tr>
<tr>
<td>Guam</td>
<td>112,600</td>
<td>701</td>
<td>161</td>
<td>2,978</td>
</tr>
<tr>
<td>Kiribati</td>
<td>162,500</td>
<td>541</td>
<td>300</td>
<td>218</td>
</tr>
<tr>
<td>Marshall Islands</td>
<td>88,100</td>
<td>811</td>
<td>109</td>
<td>3,550</td>
</tr>
<tr>
<td>Nauru</td>
<td>54,000</td>
<td>181</td>
<td>298</td>
<td>2,131</td>
</tr>
<tr>
<td>North. Mariana Islands</td>
<td>12,100</td>
<td>21</td>
<td>577</td>
<td>320</td>
</tr>
<tr>
<td>Palau</td>
<td>75,400</td>
<td>471</td>
<td>160</td>
<td>1,823</td>
</tr>
<tr>
<td>Polynesia</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>American Samoa</td>
<td>637,900</td>
<td>8,133</td>
<td>78</td>
<td>10,750</td>
</tr>
<tr>
<td>Cook Islands</td>
<td>61,400</td>
<td>200</td>
<td>307</td>
<td>390</td>
</tr>
<tr>
<td>French Polynesia</td>
<td>17,800</td>
<td>237</td>
<td>75</td>
<td>1,830</td>
</tr>
<tr>
<td>Niue</td>
<td>250,000</td>
<td>3,521</td>
<td>71</td>
<td>5,030</td>
</tr>
<tr>
<td>Pitcairn</td>
<td>1,650</td>
<td>259</td>
<td>6</td>
<td>390</td>
</tr>
<tr>
<td>Samoa</td>
<td>50</td>
<td>39</td>
<td>1</td>
<td>800</td>
</tr>
<tr>
<td>Tokelau</td>
<td>18,800</td>
<td>2,935</td>
<td>61</td>
<td>120</td>
</tr>
<tr>
<td>Tonga</td>
<td>1,500</td>
<td>12</td>
<td>125</td>
<td>290</td>
</tr>
<tr>
<td>Tuvalu</td>
<td>10,200</td>
<td>26</td>
<td>392</td>
<td>900</td>
</tr>
<tr>
<td>Wallis &amp; Futuna</td>
<td>14,800</td>
<td>255</td>
<td>58</td>
<td>300</td>
</tr>
<tr>
<td>PACIFIC ISLANDS (Total)</td>
<td>8,500,800</td>
<td>551,079</td>
<td>15</td>
<td>30,569</td>
</tr>
</tbody>
</table>

Source: Based on 1SPC (2004), and 2King (1991).
However, with regard to waste management in the South Pacific, some of the priority needs (according to Morrison and Munro (1999)) are to:

- Give waste management a higher priority in national planning;
- Develop national integrated waste management policies;
- Improve implementation of waste management strategies;
- Provide sustainable funding for these activities;
- Collect improved data on sources, pathways and impacts of wastes;
- Improve landfill management planning and operations;
- Conduct technical and economic analysis of operations to recycle metals;
- Review incinerator performance in the South Pacific;
- Provide suitable long-term storage of hazardous material while disposal mechanisms are being determined;
- Develop practices that lead to the incorporation of septic sludge into agricultural and forestry projects;
- Investigate the use of treated wastewater (effluent) on land;
- Expand training for skilled personnel to work in the waste management industry in the South Pacific; and
- Pool information on waste management in the region.

LAND-BASED ACTIVITIES THAT HARM THE CORAL REEF ENVIRONMENT

The Various Land-Based Activities

Any land-based activity that pollutes the aquatic environment has the potential to cause harm in the marine environment and coral reefs. Wastes can be classified in various ways, e.g., MNRE (undated) classified waste into four main groups namely: municipal waste, industrial waste, hazardous waste and special (or hospital) waste. However, SPREP (2003:5-6) recognized three types of wastes contributing to the pollution of the marine environment: (a) solid waste, (b) sewage and (c) other land-based sources of pollution. In particular, this paper recognizes soil particles as an important pollutant that is released into the aquatic system via various land-based activities.

Land-based activities that produce waste that can harm the coral reef environment include:

- Agriculture;
- Forestry;
- Energy development;
- Mining and minerals processing;
- Construction activities; and
- Development or extension of residential and industrial areas.

Some of the solid waste get into the marine environment via rubbish dumping into a river or stream, or directly into the sea in coastal areas. Also, wastes from livestock farms are washed into drainage systems then into natural waterways and finally into the sea. However, in view of the small size of most of the islands, the source of pollution is usually close to the sea.
Table 2. Average Biodegradation Rate of Some Rubbish that Commonly Ends Up in the Marine Environment

<table>
<thead>
<tr>
<th>Rubbish Item</th>
<th>Time Required to Break Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monofilament line</td>
<td>600 years</td>
</tr>
<tr>
<td>Polystyrene cups &amp; pellets (used in packing material)</td>
<td>500 years</td>
</tr>
<tr>
<td>Plastic six-pack packaging rings</td>
<td>450 years</td>
</tr>
<tr>
<td>Aluminium cans</td>
<td>90 years</td>
</tr>
<tr>
<td>Tin cans</td>
<td>75 years</td>
</tr>
<tr>
<td>Orange peel</td>
<td>½ year</td>
</tr>
</tbody>
</table>

Source: Based on Chapman (2003)

Chemicals are introduced into the water system mainly via agriculture, forestry, industrial discharges, mining and other activities. Naidu and Morrison (1989) have described industries likely to produce undesirable effluents in the Pacific islands, i.e., (a) brewery and distillation, (b) cane sugar manufacture, (c) metal finishing, (d) tanning, (e) food manufacturing and processing, and (f) cement. In agriculture, chemicals are used mainly as fertilizers and pesticides; in forestry they are used mainly for timber treatment; and in mining, chemicals are used in the process of extracting the mineral from the ore. Like solid waste, chemical pollutants have been a major concern for those depending on the streams and rivers as they have caused death by poisoning of fish. These pollutants can also cause harm to organisms in the marine environment. Chemicals used in fertilizers, together with natural or organic fertilizers, contribute to nutrient pollution which leads to algal blooms in the aquatic environment and reduces availability of oxygen in the water which could have a serious negative effect on the fish population. This, in turn, may influence fish and other life forms in the marine environment.

It has been pointed out in Morrison and Munro (1999) that once a contaminant enters the hydrological cycle, it can be rapidly transported within the cycle leading to contamination of sediments, rivers, lagoons, mangroves and reefs. Furthermore, untreated, industrial wastewater can have very large negative effects on the environment, e.g., the Vailima Brewery at Vaitele, Samoa, has been shown to discharge 720 kg BOD per day (equivalent to the discharge from a residential area with 10,500 domestic residents) into a local stream and hence into the sea (ADB/GWS, 1996).

Agricultural Activities and Soil Erosion in the Pacific Islands

Soil pollution in agriculture has been described by Tuivavalagi (1996), Willett and Bowmer (1989), and by Morrison et al. (1996a). Soil particles are introduced into the water system via various types of land-based activities, particularly via the process of soil erosion. Soil erosion by water or rainfall is an important issue in the high volcanic and continental islands of the Pacific – mainly as a result of activities in the agriculture, road-construction and forestry sectors. However, soil erosion may also be caused by any activity where earthwork is involved as in preparation of land for intensive agriculture or subdivision, preparation of sites for housing, construction of playgrounds for rugby, soccer, golf and other sports played in the Pacific. In many cases, soil particles are carriers for nutrients and chemical pollutants.

Some of the main pollution problems related to agricultural activities in the Pacific, as listed in Tuivavalagi (1996), are as follows:

- Poor siting of agricultural activities in relation to the environment (e.g., poultry farm upwind from a boarding school);
- Direct discharge from farms (e.g., cattle farms and piggeries) into water course;
- Excessive use of pesticide;
- Existence of large amounts of outdated and unknown pesticides;
- Improper facilities for storing unwanted and excess pesticides;
- Lack of appropriate data on pesticides (e.g., types, how much used, effects on crops, toxicity, etc.);
- Lack of community awareness; and
- Inadequate information on agricultural activities and their impact on the environment.

According to ESCAP (2000), while traditional Pacific island agricultural systems were highly sustainable, modern commercial agriculture is the most pervasive and environmentally destructive human activity in the Pacific island sub-region, resulting in, among others, the pollution of the surface and groundwater with agricultural chemicals; pollution of the wetlands and the marine environment with silt and agricultural chemicals; and the reduction of biodiversity;

In many Pacific islands, agricultural activities contribute greatly to erosion and soil loss that occur. Practically all erosion in the Pacific is due to water rather than wind and the factors contributing to the total amount of soil loss is given by the Universal Soil Loss Equation (which is discussed in many introductory soil science or fertility textbooks, e.g., Brady, (1990)) as:

\[ A = R \times K \times L \times S \times P \times C; \]

where \( A \) is the amount of soil loss, \( R \) the rainfall factor, \( K \) the soil factor, “\( L \times S \times P \)” the land management factor (where \( L \) is the slope length, \( S \) the slope steepness and \( P \) the erosion-control practice), and \( C \) the crop management factor. Once we know the factors responsible for soil loss, we can then devise technologies to reduce the amount of soil loss by reducing the value and importance of the land management and crop management factors. With regard to the \( K \) factor, it is important to realize that soils in the Pacific vary greatly and some are far more erodible and need to be treated with greater care. With regard to the \( R \) factor, we should realize that rain in many areas of the Pacific is very erosive and that it is rainfall which triggers the whole process of erosion and it is important that we try as far as possible to keep the soil covered from the effect of raindrops and rainwater. In fact if we have space for only three words to advice farmers (and other land users) on how to reduce soil loss, the advice would be: “keep soil covered”.

As discussed in Tuivavalagi et al. (2002), the three main causes of soil erosion and land degradation in the Pacific islands are: (a) natural hazards, e.g., cyclones; (b) direct causes, e.g., poor land and crop management practices, deforestation, etc.; and (c) underlying causes, e.g., population increase, land shortage, land tenure, poverty, economic pressure, etc. With regard to underlying causes, Tuivavalagi (2003a) has also pointed out the importance of worldviews, concepts, attitudes and awareness. All these potential causes of soil erosion and land degradation should be considered in designing a framework, using an integrated and multidisciplinary approach, to tackle the problem.

A number of projects have been initiated in the Pacific islands to measure soil loss via erosion in agricultural areas, e.g., the PACIFICLAND Project of the International Board for Soil Research and Management (IBSRAM) – as described in IBSRAM (1995). Soil loss from agricultural areas in Fiji vary widely; in sugarcane areas, the amount of reported losses have been 36.7t/ha/yr (Morrison, 1981), 68.8 and 77.8t/ha/yr (Liedtke, 1989); in ginger areas, the reported losses have been 21.9 t/ha/yr (Liedtke, 1988); 85.7 t/ha/yr (Morrison, 1981), and 1-300 t/ha/yr (Watling and Chape, 1992); in areas grown in taro the reported losses have been 56.0 t/ha/yr (Liedtke, 1988); and 12-300 t/ha/yr in vegetable/root crop growing area (Watling and Chape, 1992).

Despite these soil losses, there are technologies available to reduce or eliminate the problem, however, there is need for local verification trials or fine-tunings so the technology is relevant or appropriate.
Such technologies belong to two major groups, i.e., biological (or vegetative) and physical (or mechanical). The biological ones include keeping soil covered with organic matter, use of hedgerows, use of vetiver grass, contour planting, agroforestry, mulching, etc.; while the physical ones include minimum tillage, settling ponds, bench terraces, netting to cover exposed soil, silt traps, etc.

Soil loss in agricultural areas in the Pacific has been reduced by growing hedgerows of plants along contours to prevent soil from eroding down the slope. In Fiji, during 1992-97, such hedgerows reduced soil loss by 87% when pineapple was the contour plant and by 98% when vetiver grass was used as the row crop (Nakalevu, et al., 2003). In Samoa, during 1999, soil loss was reduced by 76% where erythrina was grown along contours (Hunter et al., 1999).

### CORAL REEFS AND THE MARINE ENVIRONMENT AND IMPACTS OF PRODUCTS OF LAND-BASED ACTIVITIES

King (1991) described the marine environment as consisting of: (a) the beaches and seagrass, (b) mangroves, (c) coral reefs and lagoons, (d) the open sea and (e) the food webs that link the various components. The land-based activities that impact the marine environment are those that introduce (a) solid waste, (b) chemicals and (c) soil particles into the water system. As pointed out by Chapman (2003), the ocean has long been seen as limitless and able to absorb anything that is discharged into it. However, this view is now changing in many parts of the Pacific for two main reasons – the first has to do with the increase in population while the second has to do with the increasing use of materials that take much longer to break down (see Table 2). The worst of such materials is plastic which, according to Chapman (2003), may be lying around our beaches and reefs for many hundreds of years and, because of its light weight, can be carried hundreds and even thousands of miles by ocean currents and winds.

Chapman (2003) also noted that garbage and oil can kill fish, sea turtles, dugongs, corals, invertebrates and other marine species, as detailed below:

- Sea turtles often mistake plastic bags and balloons for jellyfish which is one of their favorite foods. When they do, they die a slow and painful death because their digestive track becomes blocked;
- Marine animals such as whales and dolphins get curious with garbage items such as bait box straps and six-pack packaging and become tangled up or strangled to death as a result of playing with them;
- Other marine animals can end up with plastic beverage rings around their necks and slowly strangulate death;
- Fish, turtles, and other marine animals can get entangled in derelict fishing gear such as gill nets – which can continue “fishing” many years after being lost or discarded;
- Marine animals that encounter nets and other fishing gear can drown, lose their ability to catch food and be more susceptible to disease and predators;
- Oil can destroy seagrass beds, mangroves, corals, crustaceans (crabs and lobsters), mollusks (giant clams and trochus), and other reef organisms by smothering them and cutting off light and oxygen necessary for their survival.

In Samoa, persistent organic pollutants (POPs) have been found in marine sediments and shellfish (MNRE, 2003). Chemical pollutants can travel through the food chain and their concentration can build up to toxic levels in marine fishes.

Suspended sediment reduces photosynthetic activity in the marine environment which could affect the fish and other marine animals that depend on these sea-plants. In addition, old sediments on the
seafloor may be reworked and resuspended. Deposited particles can actually smother the sea-plants and also affect coral growth. According to SPREP (1993), corals have a number of characteristics which make them sensitive to sediment as explained below:

• Corals use their tentacles to feed on plankton and sediment interferes with feeding;
• Corals are permanently attached and cannot avoid sediment exposure;
• Free-floating coral larvae will only settle and attach to clean, sediment-free surfaces;
• Corals also have algae growing as part of their structure and the algae aid coral growth by their photosynthesis; this process is reduced in turbid, sediment-laden water.

Some corals are more sensitive to sediment exposure than others. Deposition can smother corals and long term exposure to sediments can kill all or part of the colony. Even where exposure does not kill the coral directly, it will reduce coral growth as energy is diverted from feeding to clearing sediment. Sediment exposure may also result in coral bleaching (the loss of the algae) which, in turn, has many effects, including slower growth and less deposition of the coral skeleton. A sedimentation rate of 50-100 mg of sediment per square cm per day will cause less species diversity and percent coral cover (SPREP, 1993).

Effluents from land-based activities discharged into the aquatic environment is a cause for concern as it may cause:

• Algal blooms (due to excessive nutrients) and subsequent water quality problems;
• Direct toxicity to marine organisms (due to metals, hydrocarbons, or pesticides),
• Significant bio-accumulation in food chains leading to indirect toxicity problems for fish and other life forms;
• Health problems to water users (e.g., bacteria, viruses);
• Significant changes in the redox conditions of the waters (changes in BOD, COD, and level of dissolved oxygen);
• Serious damage to marine and coastal ecosystems (due to the influence of sedimentation); and
• Damage to engineering facilities (e.g., pipelines, piers, dams) caused by changes in pH and redox conditions (Carpenter and Maragos, 1989:226).

In addition, Carpenter and Maragos (1989:254-5) have pointed out that the dynamics of coral reefs may be affected by the following:

• Excessive terrigenous or marine sedimentation that buries corals and other bottom-dwelling reef organisms and inhibits larval settlement;
• Excessive dilution of seawater from freshwater runoff;
• Circulation from winds, tidal fluctuations, and wave-driven currents;
• Eutrophication and nutrient enrichment that allow algae or other benthic organisms (sea urchins, sponges, etc.) to compete against and displace reef corals and coralline algae;
• Reduction of sunlight and consequent decreased primary productivity of reef corals and other producers on the reef;
• Frequency and magnitude of earthquakes, lava flows, and subsidence;
• Exposure to catastrophic storms and large waves;
• The capacity of landward ecosystems (mangroves, seagrasses, coastal forests) to trap sediments and control runoff of eroded soils;
• Shoreline and offshore dredging and filling that bury or remove coral communities or change currents and circulation;
• Prolonged exposure to air (lowered sea level) and high temperatures; and
• Prolonged exposure to reduced dissolved oxygen levels.
There are some basic principles that apply across islands, but it should be noted that no two islands are the same. This points to the need to understand the basic parameters of each island, including its marine environment and coral reefs, which in turn influence the impact of land-based activities.

**STRATEGIES FOR REDUCING HARMFUL EFFECT OF LAND-BASED ACTIVITIES**

**Worldviews**

Many are aware of the environmentally friendly worldview of the animistic Pacific islanders and, in one way or another, have tried to revive an environment where nature is revered. While this may look like a good idea from an environmental standpoint, it will be disastrous in other aspects. As Crocombe (2001:208) pointed out, it is indeed a good development that we have moved away from the old religious systems which included practices such as cannibalism, human sacrifices, strangling wives at the death of the husband, killing infants born to “inappropriate” parents, burying the very ill while still alive, etc.

According to Crocombe (2001:231), an expert on the sociocultural and economic life in the Pacific islands, one of the greatest needs in the Pacific today is “to evolve a new ethical system, or systems, better adapted to the present and coming context”. We argue that such a system exists in the Biblical worldview which provides a solid foundation for sustainable development (Evans et al., 2003; Miller and Guthrie, 2001). This system would be quite appropriate for the Pacific islands where 95% of the population is considered Christian (Johnstone et al., 2001). However, up to the present time, the focus of the church has been mainly on the salvation of souls, and, with regard to activities on the physical dimension, there is minimal emphasis on the teaching and propagation of the Biblical worldview with regard to the environment and other topical issues. This weakness in the current approach of the church should be addressed quickly as the islanders search for a model for sustainable development and before consumerism has even greater environmental impacts in the Pacific islands.

Tuivavalagi has talked and written on the need to consider religion, the church and particularly the Biblical worldview in the developmental processes in the Pacific islands (e.g., Tuivavalagi 1999, 2003a, 2003b). This is not a simply theoretical proposition as Ball (2003) has described how Biblical principles were used through the existing church framework to control pollution by a “land-user community” which was having serious detrimental effects on the fish catches of the downstream, “sea-user community”. Such an approach should be seriously considered in the Pacific where some farming communities are not very concerned about the environmental effect of their farming practices (e.g., Taulealea, 1997:36) and where churches and church organizations exist and the majority of the people are religious and Christian in particular. There is a need to develop collaboration with Christian Ministries or Movements that specialize in teaching the Biblical Worldview in relation to agriculture, fisheries and the environment, e.g., the Discipling Nations Alliance (http://www.disciplenations.org). Such organizations are becoming more active and 2004 meetings/ training workshops that the authors are aware of included one in Kenya (January) and others planned for the USA (April), Thailand (June) and Samoa (November).

Traditional religion, science and engineering in many Pacific island communities in pre-missionary days reflect a holistic worldview which saw a connection among all creations. The PABITRA (Pacific-Asia Biodiversity TRAnsect) Network, for example, is based on an ancient Hawaiian system of land management (Ahupua’a Resource Management System (Shea et al., 2001:39)) which sees land, from the mountain to the sea, holistically. PABITRA has been active in the field in Hawaii, Fiji and Samoa and
members are considering field activities in other countries particularly Palau or another country in Micronesia, Cook Islands and the Solomon Islands. Further details on PABITRA, are available at their website at http://www.botany.hawaii.edu/pabitra/. For various reasons, including the emphasis in modern times on specialization and compartmentalization rather than holistic thinking, people are becoming less aware of the link between the land and the sea. Such a link obviously exists and it is critical that scientists and others involved in coral reef research, monitoring and management should also have a good understanding of the land - including current and planned land-based activities and the current and potential impact of these activities on the coral reefs and marine environment.

**Other Strategies and an Integrated Approach**

The most powerful way to influence the behaviour of Pacific islanders is through their belief system – which is intimately related to their view of the world. However, the approach should be integrated and multidisciplinary in the sense that other tested strategies should be applied simultaneously, by all stakeholders, as part of a coordinated framework. Such an integrated approach has been previously discussed, e.g., by FAO and UNEP (1999), FAO (2000) and Tuivavalagi, et al. (2002).

Another powerful way to influence the behaviour of Pacific islanders is through education. For this reason, the formal and informal education systems should be involved such that both the young, starting with those entering primary schools, and the school leavers in the communities are educated.

Yet another powerful way of influencing the behaviour of Pacific islanders is through the introduction of laws, rules and regulations. These could be imposed by the government, church structure or the traditional social leadership. In Samoa, for example, Peteru (1993) has described current and planned legislations to: (a) increase harvestable stocks of fish and other marine resources; (b) conserve and protect marine breeding and feeding areas; and (c) integrate the sustainable development of marine resources with environmental planning and assessment. With regard to village-imposed regulations, coastal villages in Samoa have been made aware of the importance of sustainable development and have, themselves, introduced rules and regulations through the village *fono* (council) to control fishing activities.

We should also be aware that, apart from the *obvious or direct* causes of negative impacts on coral reefs and the marine environment, there are also *indirect or underlying* causes which might be not so obvious, e.g., a high population growth rate. These less obvious causes should also be taken into consideration when designing a strategy to minimize the negative impacts of land based activities.

Crocombe (2001:591-626) has pointed the strengths and weaknesses in the current regional approach, however, wherever appropriate, the Pacific islands should consider using a regional approach to develop strategic responses to environmental issues. The advantages of such an approach, as pointed out by Power (2002) include the:

- Sharing of high investment or establishment costs for capital intensive activities;
- Alleviation of capacity- or capability-constraints in small populations needing specialist skills or advice;
- Attaining of economies of scale in the provision of centralized training services;
- Formulation of better policies or activities that have “spill-over” or “mutually-reinforcing” impacts creating their own economies of scale; and
- Greater potential for providing a stronger voice in global forums.
Technical Consideration

Scientists, including those operating in the Pacific islands, have often placed too much emphasis on technical considerations while these can often be of much less importance, particularly in the Pacific island context. Just because someone comes up with a method of how to reduce wastes entering the water system does not mean that everyone will start using the new invention – as people have other consideration including their belief system, cultural acceptance, cost involved and other factors. This is an additional argument that supports the multidisciplinary approach whereby the natural scientists work collaboratively with social scientists, members of the local communities and other stakeholders. Nevertheless, as this is a meeting of natural scientists, some emphasis must be placed on technical consideration.

With regard to technical considerations, some of the steps to be undertaken include:

(a) Consider the problems in the marine and coral reef environment and identify those that may be due to land-based activities; Monitor these problems;
(b) Consider the various land based activities and identify those that may be contributing pollutants to the water system; Monitor these activities and their level of effluents;
(c) Identify, develop or fine-tune technologies to reduce pollutants entering the water system; Monitor effect of these technologies;
(d) To avoid wasting resources on “re-inventing the keel”, we should make a thorough review of the literature and relevant unpublished documents – including action plans for pollution control by national governments and (sub)regional bodies, e.g., Samoa’s biodiversity strategy and action plan (Schuster et al., 2001), SPREP’s action plan for managing the environment of the Pacific islands region (SPREP, 2000) and others.

MNRE (undated) has mentioned four simple methods for minimizing waste, namely: (a) reuse, (b) recycle, (c) compost and (d) recover. It is more effective to deal with the pollutants before they enter the aquatic environment; however, in line with the comprehensive and integrated approach, consideration should also be given to addressing pollutants that have entered the aquatic environment. For example, it is known that mangroves can play an important role in trapping sediments and thereby protect the fringing coral reefs and marine environment from excessive sedimentation. Protection of mangroves and other strategies should be considered.

Soil erosion is a serious global problem and such erosion due to rainfall is a serious problem in the high volcanic and/or continental islands of the Pacific. There are two main methods of dealing with such soil loss – the mechanical method or the natural or vegetative method. After years of research and field observations and millions of dollars worth of construction works, data gathered from various parts of the world confirm that the natural or vegetative method is more effective (Tuivavalagi et al., 2002). The Vetiver System, an effective way of controlling soil loss and protecting water quality, has been gaining popularity worldwide. It is quite appropriate for the Pacific islands and is discussed further in the next section. However, experience in Samoa and Fiji (Nakalevu et al., 2003) show that the technologies employed have to blend long-term conservation with shorter-term cash benefits. For this reason possible ways of using vetiver grass as a source of income should be explored; however, it is possible to use this grass as a thatch and as a raw material for making baskets and many other handicraft items – as explained by Howlette (1996:40) and the Vetiver Network website.
THE VETIVER SYSTEM FOR REDUCING SOIL LOSS FROM LAND-BASED ACTIVITIES

Figure 1. Geographical location of areas where the Vetiver System has been introduced around the world. Source: The Vetiver Network Website, www.vetiver.org (courtesy of D. Rachmeler, President & Coordinator).

The Vetiver System is recent (less than 10 years old) but during this short lifespan, it has been introduced into over 100 countries (Rachmeler, 2004). The system has been described by TVN (2004a) as a low cost, and extremely effective system for soil and water conservation and infrastructure stabilization, pollution control, and waste water treatment. The system uses vetiver grass, *Vetiveria zizanioides*, for all its bioengineering and conservation applications.

The vetiver grass, *Vetiveria zizanioides*, is unique and TVN (2004a) reports that it can be used in the tropics, semi tropics and even in areas outside the semi tropics where there are hot summers, and winters that do not include permanently frozen soil conditions. The roots of the grass improve the shear strength of soil by 30 and 40% and engineers liken it to a “Living Soil Nail” (TVN, 2004a). For this reason, apart from being used for soil conservation, the grass is now considered important for the stabilization of road and railroad embankments, river banks, canals, bridge abutments, landslide prevention, as well as for water quality improvement, waste management and other uses.

Howlett (1996:40) has described the most important concerns by governments and farmers, regarding the introduction of vetiver: (a) that it might escape and become invasive; (b) that it might be a host for certain pests and/or diseases; and (c) it does not generate any income. However, as pointed out by TVN (2004b), vetiver does not escape (as it does not produce fertile seeds and has a non-spreading root system) and does not have any serious pest or disease.

Chomchalow and Chapman (2004) have mentioned that “[t]he present campaign on planting of vetiver in agricultural and non-agricultural areas for soil and water conservation has met with some problems in that the growers are not willing to plant vetiver as there is no direct income derived from the planting.” However, in their paper, Chomchalow and Chapman (2004) added that, in addition to being used to perform specific functions in soil and water conservation, environmental protection, etc., vetiver plant
has also a few other uses, e.g. as forage for livestock, ornamentals, and miscellaneous other uses. Harvested vetiver leaves, culms and roots are utilized after some degree of processing in various ways, e.g. as input of agriculture-related activities (mulch, compost, nursery block / planting medium, animal feed stuff, mushroom cultivation, botanical pesticides, and allelopathy), handicraft and art works, medicinal applications, fragrance, input of construction-related activities (roof thatch, hut, mud brick, vetiver-clay composite storage bin, veneer / fiber board, artificial pozzalans, ash for concrete work, and straw bale), containers (pottery, melamine utensils, water containers), bouquet, energy sources (ethanol, green fuel), industrial products (pulp and paper, panel), and miscellaneous other utilization. For vetiver grass to be successfully introduced into the Pacific islands, it is important that appropriate potential uses should be explored.

Vetiver thrives over a wide range of ecological conditions but was once thought to be confined to wetlands (TVN, 2004b). The grass grows in highly acidic soils (pH<4) and alkaline soils (pH=11) and its roots can grow to depths of 3-4 m. The grass is easy and cheap to establish, and needs minimum maintenance while each clump of vetiver is so dense that, if configured correctly, it will act as a near perfect natural water filter.

Vetiver grass could be planted as a contour hedge where it will act as a continuous filtering system, slowing down rainfall runoff, reducing rilling and gullying, and collecting soil sediments at the hedge face (TVN, 2004b). This reduces the loss of soil and nutrients while soil moisture and groundwater may be improved significantly – while natural terraces and ground leveling develops behind the hedge (see Figure 2b). Another feature of the grass is that it takes up minimal space and is virtually non competitive with adjacent crops.

Grimhaw (2003) describes how vetiver has developed as world technology over four phases of application: (1) soil and water conservation in poor rural areas; (2) infrastructure stabilization; (3) rehabilitation of difficult and often polluted sites; and lastly (4) water quality enhancement and site rehabilitation in relation to industry and intensive commercial agriculture.
TVN (2004c) gives details of the proceedings of the third international Vetiver Conference that was recently held in Guangzhou, China. The papers presented have been organized in the website into 8 sections including: (1) vetiver and water (21 papers); (2) stabilization and erosion control (20 papers); (3) land rehabilitation and phytoremediation (27 papers); and five other sections.

Lotter (2004) has provided an update on vetiver research. In addition, recent studies in Fiji showed that the introduction of contour hedgerows of vetiver and pineapple results in 95% reduction in soil loss compared to soil losses recorded in farmers plots without the hedgerows (Nakalevu et al., 2003). Vetiver grass has a long history in Fiji where it has been promoted as early as 1946 (Nakalevu et al., 2003) but then it became a forgotten plant for some time before its recent “rediscovery”. Those wishing to consider using the Vetiver System should contact The Vetiver Network at http://www.vetiver.org for detail.

CONCLUSIONS AND RECOMMENDATIONS

Damage to the coral reefs and marine environment may be caused by land-based activities. The approach to solving this problem should be integrated and multidisciplinary involving all stakeholders in a coordinated framework of activities that also include the monitoring of the situation and activities (current and planned) in the coral reefs, marine environment and particularly on land. The potential influence of the church and a regional approach should also be considered.

ACKNOWLEDGEMENTS

The authors appreciate comments by Mr. Bill Cable, the POPs Project Coordinator, MNRE, Apia, Samoa who read an early manuscript of the paper.

REFERENCES


Liedtke, H. 1988. Soil erosion on the fields of indigenous Fijians in the area of Suva (Fiji). In: Liedtke, H. and Glathar, D. Report about two research projects in the Republic of Fiji, Sponsored by the German Research Foundation. Geographical Institute, Ruhr University, Bochum. pp. 1-51

Downloaded 2nd February 2004.


Rachmeler, D. 2004. Personal communication by email on 19 January 2004 with Dale Rachmeler, President and Coordinator of The Vetiver Network.


TVN, 2004c. Proceedings of the Third International Vetiver Conference, Guangzhou, China


Annual Reproduction Cycle of *Acanthaster planci* (L.) in Palau

*David Idip Jr.*
Palau International Coral Reef Center
PO BOX 7086 Koror, Palau 96940    Email: didip@picrc.org

**ABSTRACT**

This study determines the annual reproductive cycle of *Acanthaster planci* (L.) in Palau. A total of 472 *A. planci* was collected over a two-year period, from May 2001 to April 2003. Based on the information derived from the mean gonad index we were able to determine the annual spawning pattern of *A. planci*. The information illustrates that there are two major spawning periods per year. The first spawning event occurs over several months, starting in either March or April and ending in June or July. The second event occurs only over a one-month period in September. Evidence also suggests the possibility of a third, but minor spawning in December and January.

**INTRODUCTION**

The reproductive occurrence has always been considered an important issue when dealing with *Acanthaster planci* (L.) outbreaks (Babcock and Mundy, 1992). These issues are not only limited to the biological point of view but also from the management standpoint when deciding the most effective time to concentrate and intensify control measures (Yamazato and Kiyan, 1973). *Acanthaster* relies on corals as a source of food and has devastated reefs in Guam, Hawaii and Australia (Branham *et al.*, 1971). Palau is no stranger to this natural phenomenon, *Acanthaster* outbreaks occurred in the late 1960’s and the early 1970’s (Tsuda, 1971). But by far, the largest outbreak was the 1979 event in which 51,587 starfish were collected on Ngederak reef and the surrounding reefs over a 12-day period (Birk, 1979).

Early studies done in Guam by Chesher (1969) and Cheney (1974) reveal that *Acanthaster* has one spawning event per year from late September to December. Yokochi and Ogura (1987) determined that June and July was the breeding season for *Acanthaster* in Okinawa. How will Palau’s spawning cycle compare to these areas? According to Yamazato and Kiyan (1973) *A. planci* has extended a spawning season at lower latitudes whereas it is much shorter and more defined spawning season at higher latitudes. The information derived from this study supports the first half of the previous statement. *Acanthaster planci* has two major spawning periods and a possible third minor breeding period.

**MATERIALS AND METHODS**

**Sites**

*Acanthaster planci* were sampled from two locations situated in Koror, Palau. Ngesekeasau reef (7°18’29. 58”N, 134°30’34. 19”E) is an exposed fringing reef flat located east of Koror (Fig.1). This area was heavily infested in 2000 and 2001, but due to local clean-up efforts the entire population was removed. Limited surveys of the area have shown no signs of crown-of-thorns. Lighthouse reef (7°16’38. 38”N, 134°27’18. 28”E) is an exposed fringing reef situated about 5 kilometers south of Ngesekeasau and about 4 kilometers east of Malakal harbor. This area was one of the most heavily infested reefs during the 1979 *Acanthaster* outbreak. Even with several clean-up efforts, currently this reef is still heavily
infested.

Figure 1. Map showing location of sites. Large circles indicate collection sites

**Sampling Method**

At least 20 *A. planci* were collected and dissected at 1-month intervals from May 2001 to April 2003. All Months were sampled except for October and November of 2001. The samples were collected on the reef flat, where maximum depth did not exceed 2 meters, and were immediately transported to the laboratory and kept in an open circulation saltwater tank. Prior to dissection the animal’s weight, diameter and the number of arms were recorded. Each animal was sexed by examining the dissected gonads under a dissecting microscope. The gonad index was computed using the following formula:

\[
\frac{\text{Total Weight of Gonad}}{\text{Total Weight of Starfish}} \times 100 = \text{Gonad Index}
\]

The total sample size was 472 individuals of these 258 were males and 214 were females. The animals
ranged from 20 cm to 39 cm in diameter with a mean of 29.3 cm. Animals less than 20 cm were not utilized because they were considered immature (Cheney, 1974). The weight ranged 228 grams to 2820 grams with a mean of 895 grams.

RESULTS AND DISCUSSION

Changes in seasonal mean gonad indices for 2001 and 2002 are shown in Fig. 2. In the first year (May 2001 to April 2002) the gonads peaked in May and consequently dropped to minimum levels in June. The index then immediately increased gradually in July with a subsequent steep increase in August, reaching maximum levels in September. Data from October and November are missing, but based on second year data it is assumed that the index would immediately plunge to low levels in October and then gradually rise in November. January saw a slight dip in the index and afterward it increased sharply reaching a maximum value in March. The gonad then decreased gradually over the next three months, reaching minimum values in June. Data from Year 2 (May 2002 to April 2003) is identical to Year 1 information except for a slight shift in the mean peak from March in Year 1 to April in Year 2.

Figure 2. Mean Gonad indices for *A. planci* from Palau, two sites combined, from May 2001 to April 2003. (No data for October and November 2001)

The results of the seasonal variation in gonad indices show that *Acanthaster planci* have two major spawning periods and one possible minor spawning event during the year. The first spawning event is broad, spanning over several months. In the first year of the study the spawning event started in March and concluded in June. The second showed a slight shift in the onset of the spawning period from March to April. The second spawning event is much shorter and more defined, lasting only one month (September). The third possible spawning period is a minor occurrence that is not well defined and ensues during the months of December and January.
Fig. 3 displays the mean water temperature for Malakal harbor and Lighthouse Reef. Mean water temperature was usually between 28.5°C and 30.5°C during the spawning periods. The shift in the spring spawning period from March in the first year to April in the second year can be explained by the temperature profile. In March of 2002 the mean water temperature for March (Peak spawning period) was around 29°C, but in March of 2003 (No Spawning) the mean temperature was 28°C. This suggests that the *Acanthaster* breeding in Palau maybe limited to water temperature above 28°C.

![Temperature graph](image)

**Figure 3.** Monthly water temperature means from Malakal harbor and Lighthouse Reef. PSP=Peak Spawning Period, MSP=Possible Minor Spawning Period

**ACKNOWLEDGEMENTS**

The author wishes to thank Ken Okaji for his help and guidance during the course of this project. I would also like to thank Jim Kloulechad, Terri Brugh and all the local high school students who were involved in this project, for assistance in the field and laboratory.

**REFERENCE**


Chesher RH (1969) Destruction of Pacific Corals by the Sea Star *Acanthaster planci*  
Science 169: 280-283

Tsuda RT (1971) Status of *Acanthaster planci* and Coral Reefs in the Mariana and  


Yokochi H, Ogura M (1987) Spawning Period and Discovery of Juvenile *Acanthaster planci* (L.) (Echinodermata: Asteroidea) at Northwestern Iriomote-Jima,  
ABSTRACT

The Rock Islands-Southern Lagoon Area (RISLA) of Koror State is internationally known for its spectacular beauty both above and below the water. As a world-class dive destination, the area provides the foundation for Palau's tourism industry and in turn, the nation's economy. In addition to eco-tourism, subsistence and commercial use of the area's natural resources contributes to the nation's economy. But the value of the RISLA to Palau goes far beyond economics. The area is also an integral part of Palau's cultural heritage, contributes significantly to Palau's biological diversity, and provides important habitat for threatened and endangered species. Consequently, the need to properly manage and maintain the ecological integrity of the area is vital for the well being of Palau's economy, culture and diversity.

The impetus for this work did not come solely from scientists. Both the traditional and elected leadership at the Koror State and national level have recognized the cultural, biological and economic value of maintaining the ecological integrity of the area. As a result, Koror State Government, with assistance from The Nature Conservancy, is in the process of developing a comprehensive management plan for the RISLA. The Conservancy’s Conservation Area Planning tool has been used to identify key species and ecological systems within the RISLA and the main threats to each of these. The tool has been useful in identifying and prioritizing the management issues and actions needed to reduce the key threats to biological diversity. The tool however does not directly address socio-economic issues. To identify socio-economic concerns, Koror State has conducted consultations with community groups and all stakeholder groups who utilize the areas resources. We will discuss our progress to date, the challenges we have faced, information gaps and the key management issues that the state will need to address.
Assessing the bioavailability of phosphorus in sediments eroded from agricultural soils to marine systems

Katherine Chaston\textsuperscript{a}, William Dennison\textsuperscript{b} and Phil Moody\textsuperscript{2}

\textsuperscript{1}Department of Botany, The University of Queensland, Brisbane, Queensland, Australia 4072
\textsuperscript{2}Resource Sciences Laboratories, Department of Natural Resources, Indooroopilly, Queensland, Australia 4068
\textsuperscript{a}Current address: Koror State Department of Conservation and Law Enforcement, P.O. Box 116, Koror, Republic of Palau 96940 E-mail: kathchaston@hotmail.com
\textsuperscript{b}Current address: University of Maryland Center for Environmental Science, P.O. Box 775, Cambridge, MD, USA, 21613

ABSTRACT

Nutrient run-off from agricultural land has been implicated as a major non-point source of phosphorus discharged into aquatic environments. When fertilized agricultural soils enter into aquatic systems (e.g. streams, rivers, estuaries and the coastal ocean), phosphorus sorbed onto soil particles or contained within the matrix of the soil is released. Some fraction of this phosphorus can be utilized by aquatic plants often leading to adverse environmental impacts such as reduction in water quality. Chemical extraction techniques that measure P in runoff and sediments have provided little information on biologically available P, particularly when soils/sediments move from an agricultural setting to freshwater, estuarine and marine systems.

We have identified a suitable chemical extraction technique that represents the bioavailable phosphorus in sediment. Suspended sediments were simulated from 6 different soil types of the Maroochy River Catchment in Australia, a subtropical coastal catchment influenced by agriculture. Biological assays using the marine alga \textit{Skeletonema costatum} were used to measure bioavailable P in the sediments. Sediments were used as the sole P source in the bioassays. Bioassay results were correlated with several commonly used chemical techniques (total P, inorganic and organic P extracted by 0.5M NaHCO$_3$, Fe-oxide extractable inorganic P and rate of P desorption) to rank their effectiveness. Bioassays correlated best with Fe-oxide extractable inorganic P and lowest with total P (low discrimination at (1000mg/kg total P). The latter is the most commonly used method for assessing the likely impact of soil erosion on aquatic ecosystems. The identification of the bioavailable fraction of phosphorus is crucial for effective management of water quality and agricultural practices.
Timing of coral spawning in Palau

*Lolita Penland, Jim Kloulechad and David Idip Jr.*
Palau International Coral Reef Center
PO Box 7086, Koror, Palau 96940   Email: lpenland@picrc.org

ABSTRACT

Previous studies on timing of coral reproduction in Palau indicate that spawning is asynchronous and occurs over a minimum of four months. These results have been used to support the theory that there is a latitudinal effect on the degree of synchrony in coral reproduction with less synchrony near the equator. In this study we examined the patterns and timing of coral reproduction in Palau using data collected from 74 scleractinian species. Reproductive activity of broadcast spawning species was recorded from the first to the seventh evening after full moon from May 2002 to September 2002 and from February 2003 to July 2003. The Acroporidae had the most extensive reproductive season ranging from February to April then again in August to September. Acroporid species spawned from the first through to the sixth night after full moon. Bimonthly mass spawning was observed for Acroporidae in March/April and in August/September. In contrast, non-acroporid corals have a short breeding period but do participate in synchronized mass spawning. In two years of observation the mass spawning event for the non-acroporid population was consistently split over two months (April/May) and peaked on the third to fifth night after full moon. A difference in the timing of gamete release on a mass spawning evening appeared to be the general pattern for this coral assemblage.

INTRODUCTION

Recent studies from Solomon Islands (Baird et al. 2001) and Singapore (Guest et al. 2002) challenge earlier assertions that degree of synchrony in coral reproduction becomes less and reproductive season becomes longer closer to the equator (Oliver et al. 1988; Kenyon 1995). Data from the Central Pacific (Richmond and Hunter 1990) support the latter theory. Data collected from the region for 28 broadcast spawning species indicated a trend of asynchronous spawning while reports from Guam show the duration of the spawning season to extend over 3 months from June to August (Richmond and Hunter 1990; Kenyon 1994). Although data on reproductive biology for corals from Palau exists, the data is predominantly for brooding species (Abe 1937; Kawaguti 1937; 1944; Atoda 1947a; 1951a). Thus the trend for broadcast spawning species in the Central Pacific was determined using data primarily from Guam to represent the whole region. Data from other locations in the Central Pacific was needed to establish regional patterns of coral reproductive behavior.

Since the Richmond and Hunter review (1990), there has been one study conducted in Palau on scleractinian corals (Kenyon 1995). During the course of a 5-week study, 26 broadcast spawning species were examined of which 6 species were observed to spawn and 7 species were inferred to spawn following the May and June full moon. The remaining 13 species didn’t have gravid colonies during the sampling period. The implication was that asynchronous spawning with an extended reproductive season were the patterns for Palau. This new evidence confirmed the earlier trends described by Richmond and Hunter (1990). Further research is required to rule out the possibility of synchronized mass spawning events occurring at other times of the year and to ascertain annual patterns of reproduction.

The purpose of the present study was to document reproductive activity for broadcast spawning species,
to determine the extent of the reproductive season, and to assess if synchronous multi-specific spawning does occur in Palau. The timing for this research is opportune and critical as Palau’s reefs were badly damaged by the 1998 El-Nino Southern Oscillation event. Up to 68% of live coral was reportedly bleached during the summer of 1998 (Bruno et al. 2001) with mortality recorded at 100% for some species at some sites (Houk 1999). It is imperative to determine if there are healthy, reproductive coral communities that are able to produce viable larvae to re-seed Palau’s reefs. Additionally, elucidating reproductive cycles and degree of spawning synchrony has important implications for understanding life-history strategies of corals in tropical latitudes for which there is sparse information.

METHODS

Study sites

The reproductive activity for numerous coral species was documented at two study sites. Site #1 (7 19.47N, 134 29.62E) is a fringing reef in a sheltered lagoon (Nikko Bay). Coral cover at this site is 70% with the families, Faviidae, Mussidae, Pectiniidae, Merulinidae, and Agariciidae dominant. Site #2 (7 18.28N, 134 27.25E) in contrast is a fringing reef in an exposed channel area (Lighthouse channel). This site supports predominantly acroporid corals with approximately 70% coral cover. At both sites monitoring was conducted at depths of 0-6m. The two sites were selected with the intention of studying a wide range of coral species rather than comparing reproductive timing for the same coral populations at different locations.

Sampling methods

For 7 consecutive evenings following the full moon each month, field observations were conducted from sunset to 10:00pm. If colonies were observed spawning, the time of spawning and gamete type were recorded. The colonies were photographed and specimens collected for identification (No specimens were collected during the first survey, May 2002 and August 2002 specimens were lost). Colonies that spawned were tagged to determine if they underwent another gametogenic cycle within the year. However, the tags did not last more than a few months so the question remains unanswered. The priority was to record activity of many different species so that data on number of colonies for a given species was not well documented.

Spawning behavior was recorded during field surveys in May thru September 2002 and in February thru July 2003. Due to inclement weather no data was collected for Site #2 in June and July 2002. Also, due to staff limitations, monitoring at Site #2 was terminated after April 2003.

RESULTS AND DISCUSSION

Acroporid corals

Spawning activity was recorded for 14 species of Montipora (Table 1). Spawning occurred 1-3 nights following full moon from 7-9 pm. Ten species spawned in the March/April breeding season and 10 species in September, which indicates a high degree of reproductive synchrony in two distinct spawning events.
Table 1. Spawning observations for *Montipora*. Data combined from the two sites. All species had tan colored gametes. $n =$ number of colonies observed to spawn. Sex; H = Hermaphroditic. Number in parenthesis is the night after full moon when spawning was observed.

<table>
<thead>
<tr>
<th>Species</th>
<th>$n$</th>
<th>Month</th>
<th>Time</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Montipora aequituberculata</em></td>
<td>2</td>
<td>September (2,3)</td>
<td>7:00-8:10</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora altasepta</em></td>
<td>1</td>
<td>February (2)</td>
<td>7:30-8:30</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>September (2)</td>
<td>7:00-8:00</td>
<td></td>
</tr>
<tr>
<td><em>Montipora cactus</em></td>
<td>3</td>
<td>February (2)</td>
<td>7:30-8:30</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>March (2)</td>
<td>7:15-8:15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>April (1,2,3)</td>
<td>7:10-9:00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>September (2,3)</td>
<td>7:00-8:10</td>
<td></td>
</tr>
<tr>
<td><em>Montipora crassituberculata</em></td>
<td>1</td>
<td>March (2)</td>
<td>7:15-8:15</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>April (1,2)</td>
<td>7:10-8:00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>September (2)</td>
<td>7:00-8:00</td>
<td></td>
</tr>
<tr>
<td><em>Montipora digitata</em></td>
<td>1</td>
<td>February (2)</td>
<td>7:30-8:30</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>March (1,2)</td>
<td>7:15-8:45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>April (2)</td>
<td>7:10-7:45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>September (1)</td>
<td>7:30-8:30</td>
<td></td>
</tr>
<tr>
<td><em>Montipora efflorescens</em></td>
<td>1</td>
<td>September (3)</td>
<td>7:00-8:10</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora gaimardi</em></td>
<td>1</td>
<td>April (2)</td>
<td>7:10-7:45</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora grisea</em></td>
<td>1</td>
<td>March (2)</td>
<td>7:15-8:15</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora hirsuta</em></td>
<td>1</td>
<td>March (1)</td>
<td>7:30-8:45</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora hispida</em></td>
<td>1</td>
<td>February (2)</td>
<td>7:30-8:30</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>March (1,2)</td>
<td>7:15-8:45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>April (1,2)</td>
<td>7:10-8:00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>September (2,3)</td>
<td>7:00-8:10</td>
<td></td>
</tr>
<tr>
<td><em>Montipora malampaya</em></td>
<td>2</td>
<td>March (2)</td>
<td>7:15-8:15</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>April (1,2)</td>
<td>7:10-8:00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>September (1,2,3)</td>
<td>7:00-8:30</td>
<td></td>
</tr>
<tr>
<td><em>Montipora n. sp.</em></td>
<td>1</td>
<td>March (2)</td>
<td>7:15-8:15</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora samarensis</em></td>
<td>1</td>
<td>September (3)</td>
<td>7:00-8:10</td>
<td>H</td>
</tr>
<tr>
<td><em>Montipora stellata</em></td>
<td>3</td>
<td>February (2)</td>
<td>7:30-8:30</td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>March (2,3)</td>
<td>7:15-8:30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>April (2)</td>
<td>7:10-7:45</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>September (2,3)</td>
<td>7:00-8:10</td>
<td></td>
</tr>
</tbody>
</table>

Spawning was split between two months, March and April, in all but one species. Reproductive activity for this genus was recorded in 4 different months. Four species, *Montipora stellata*, *M. hispida*, *M. digitata*, and *M. cactus*, released gametes four months out of the six months of the study while *M. crassituberculata* and *M. malampaya* spawned in three months of the six months for which data was collected. One implication is that colonies of species that participate in mass spawning events also spawn at other times of the year as suggested by Baird et al. (2002). Overall, these results suggest an extensive reproductive period with the possibility of more than one gametogenic cycle for *Montipora*.
Nevertheless, synchronized spawning of *Montipora* does occur twice a year. Biannual spawning of *Montipora* spp. has been recorded from the Great Barrier Reef (Stobart et al. 1992).

Gamete release was observed for 20 species of *Acropora* (Table 2). Eighteen species spawned 1-3 nights following full moon in March and April between 7:15-9:00pm. Two species spawned 6-7 nights after the August full moon. *Acropora echinata, A. formosa, A. grandis, and A. longicyathus* were recorded spawning in March and April. This indicates that split spawning occurs for these four species. Monitoring at the *Acropora* site was conducted for only 2 evenings in March so the data set is incomplete. With further sampling, we predict that more than four *Acropora* species will exhibit split spawning during the March/April reproductive season. A similar pattern of split spawning over consecutive months has been reported for *Acropora* spp. in Okinawa (Shimoike et al. 1992). Like the genus *Montipora*, *Acropora* displays synchronous gamete release over two consecutive months. Whether there is more than one gametogenic cycle and whether a second mass spawning occurs for this genus remains to be investigated.

<table>
<thead>
<tr>
<th>Species</th>
<th>n</th>
<th>Month</th>
<th>Time (pm)</th>
<th>Sex</th>
<th>Gamete Color</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Acropora acuminata</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora cerealis</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora divaricata</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora echinata</em></td>
<td>4</td>
<td>March (3)</td>
<td>7:15-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora formosa</em></td>
<td>4</td>
<td>March (3)</td>
<td>7:15-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora grandis</em></td>
<td>1</td>
<td>March (3)</td>
<td>7:15-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora humilis</em></td>
<td>3</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora intermedia</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora longicyathus</em></td>
<td>2</td>
<td>March (3)</td>
<td>7:15-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora loripes</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora nasuta</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora polystoma</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora pulchra</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora selago</em></td>
<td>2</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora sp.1</em></td>
<td>4</td>
<td>August (6)</td>
<td>8:45-9:30</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td><em>Acropora sp.2</em></td>
<td>5</td>
<td>August (7)</td>
<td>8:15</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td><em>Acropora spicifera</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora subglabra</em></td>
<td>3</td>
<td>March (3)</td>
<td>7:15-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora vaughani</em></td>
<td>1</td>
<td>March (3)</td>
<td>7:15-9:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><em>Acropora verweyi</em></td>
<td>1</td>
<td>April (1)</td>
<td>7:30-9:00</td>
<td>H</td>
<td></td>
</tr>
</tbody>
</table>
Non-acroporid corals

At Site #1, the reproductive activity of 40 species was documented (Table 3). Data for 21 genera in 8 families indicate a synchronous mass spawning event in April/May. The majority of spawning activity was observed 3-5 nights following full moon.

Table 3: Timing of spawning for coral species at Site #1. Data pooled for 2002 and 2003. Data for Montipora not included (see Table 1). *n* = number of colonies observed to spawn. Number in parenthesis is the night after full moon when spawning was observed. Sex; H = Hermaphroditic, G = Gonochoric.

<table>
<thead>
<tr>
<th>Species</th>
<th>n</th>
<th>Month</th>
<th>Time (pm)</th>
<th>Sex</th>
<th>Gamete Color</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACROPORIDAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anacropora</td>
<td>1</td>
<td>July (1)</td>
<td>7:55</td>
<td>H</td>
<td>tan</td>
</tr>
<tr>
<td><strong>AGARICIIDAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pachyseris foliosa</td>
<td>1</td>
<td>May (5,6)</td>
<td>6:20</td>
<td>G</td>
<td>eggs- pale pink</td>
</tr>
<tr>
<td>Pachyseris speciosa</td>
<td>12</td>
<td>May (4,5,6)</td>
<td>6:20-7:40</td>
<td>G</td>
<td>sperm-brown cloud; eggs-white</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>June (4)</td>
<td>7:35</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><strong>FAVIIDAE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyphastrea microphthalm</td>
<td>2</td>
<td>May (5)</td>
<td>8:02</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Cyphastrea serailia</td>
<td>2</td>
<td>May (4,6)</td>
<td>7:35</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Echinopora lamellosa</td>
<td>2</td>
<td>May (4,5)</td>
<td>7:35</td>
<td>H</td>
<td>pale pink</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>April (4)</td>
<td>7:45</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Favia favus</td>
<td>1</td>
<td>May (4)</td>
<td>7:05</td>
<td>H</td>
<td>green</td>
</tr>
<tr>
<td>Favia speciosa</td>
<td>8</td>
<td>May (3,4,5)</td>
<td>7:00-8:30</td>
<td>H</td>
<td>green</td>
</tr>
<tr>
<td>Favites abdita</td>
<td>5</td>
<td>May (3,4,5)</td>
<td>7:50-8:35</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Favites complanata</td>
<td>2</td>
<td>May (3,4)</td>
<td>8:35</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Favites halicora</td>
<td>12</td>
<td>May (3,4,5)</td>
<td>8:05-9:00</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Favites pentagona</td>
<td>2</td>
<td>May (3,4)</td>
<td>8:06-8:31</td>
<td>H</td>
<td>pale yellow/pink</td>
</tr>
<tr>
<td>Goniastrea aspera</td>
<td>14</td>
<td>May (3,4,5)</td>
<td>8:20-9:05</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>April (3)</td>
<td>8:33</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Goniastrea australensis</td>
<td>1</td>
<td>May (4)</td>
<td>8:10</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Goniastrea edwardsi</td>
<td>7</td>
<td>May (3,4,5)</td>
<td>8:02-8:35</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Goniastrea palauensis</td>
<td>1</td>
<td>May (5)</td>
<td>8:45</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Goniastrea pectinata</td>
<td>1</td>
<td>May (4)</td>
<td>8:30</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Goniastrea retiformis</td>
<td>3</td>
<td>May (3,4)</td>
<td>8:05-8:20</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td>Leptastrea purpurea</td>
<td>1</td>
<td>April (3)</td>
<td>9:20</td>
<td>G</td>
<td>sperm- brown cloud</td>
</tr>
<tr>
<td>Leptastrea transversa</td>
<td>1</td>
<td>April (4)</td>
<td>9:19</td>
<td>G</td>
<td>sperm- brown cloud</td>
</tr>
<tr>
<td>Montastrea magnistellata</td>
<td>2</td>
<td>April (3)</td>
<td>8:40</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>May (3,4)</td>
<td>8:20-8:50</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td>Platygyra pini</td>
<td>10</td>
<td>May (3,4,5)</td>
<td>7:15-8:15</td>
<td>H</td>
<td></td>
</tr>
</tbody>
</table>
### Table 3. (Continued)

<table>
<thead>
<tr>
<th>Species</th>
<th>n</th>
<th>Month</th>
<th>Time (pm)</th>
<th>Sex</th>
<th>Gamete Color</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fungiaidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ctenactis sp.</em></td>
<td>2</td>
<td>April (4)</td>
<td>8:39</td>
<td>G</td>
<td>sperm- brown cloud; eggs- white</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>May (4)</td>
<td>8:57</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><em>Fungia fungites</em></td>
<td>1</td>
<td>May (4)</td>
<td>7:50</td>
<td>G</td>
<td>sperm- brown cloud</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>eggs-pale pink</td>
</tr>
<tr>
<td><em>Fungia sp.</em></td>
<td>2</td>
<td>April (3)</td>
<td>7:12-7:20</td>
<td>G</td>
<td>pink</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>May (5)</td>
<td>7:20</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><em>Sandalolitha sp.</em></td>
<td>4</td>
<td>May (5)</td>
<td>8:45-9:10</td>
<td>G</td>
<td>sperm- brown cloud; eggs- white</td>
</tr>
<tr>
<td><strong>Merulinidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Merulina ampliata</em></td>
<td>3</td>
<td>April (3,5)</td>
<td>7:39-7:45</td>
<td>H</td>
<td>pink</td>
</tr>
<tr>
<td></td>
<td>33</td>
<td>May (2,3,4,5,6)</td>
<td>7:15-8:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>June (3)</td>
<td>7:45</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><strong>Mussidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Lobophyllia corymbosa</em></td>
<td>3</td>
<td>May (4)</td>
<td>6:30</td>
<td>H</td>
<td>sperm-brown cloud; eggs-tan</td>
</tr>
<tr>
<td><em>Lobophyllia hemprichii</em></td>
<td>5</td>
<td>May (4,5)</td>
<td>6:25-6:54</td>
<td>H</td>
<td>sperm-brown cloud; eggs-tan</td>
</tr>
<tr>
<td><strong>Pectiniidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mycedium robokaki</em></td>
<td>1</td>
<td>May (4)</td>
<td>7:40</td>
<td>H</td>
<td>pale pink</td>
</tr>
<tr>
<td><em>Oxypora lacera</em></td>
<td>1</td>
<td>May (5)</td>
<td>8:15</td>
<td>H</td>
<td>pale pink</td>
</tr>
<tr>
<td><em>Echinophyllia sp.</em></td>
<td>1</td>
<td>May (5)</td>
<td>8:20</td>
<td>H</td>
<td>pale yellow</td>
</tr>
<tr>
<td><em>Pectinia alcicornis</em></td>
<td>2</td>
<td>April (3)</td>
<td>7:52</td>
<td>H</td>
<td>pale pink</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>May (4,5)</td>
<td>7:20-8:00</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>June (4)</td>
<td>8:14</td>
<td>H</td>
<td></td>
</tr>
<tr>
<td><strong>Poritidae</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Goniopora sp.</em></td>
<td>2</td>
<td>May (6)</td>
<td>6:40</td>
<td>G</td>
<td>sperm- brown cloud</td>
</tr>
<tr>
<td><em>Porites cylindrica</em></td>
<td>4</td>
<td>April (3,4)</td>
<td>8:00-8:13</td>
<td>G</td>
<td>sperm- brown cloud; eggs- white</td>
</tr>
<tr>
<td><em>Porites lobata</em></td>
<td>1</td>
<td>May (4)</td>
<td>9:10</td>
<td>G</td>
<td>sperm-brown cloud</td>
</tr>
<tr>
<td><em>Porites rus</em></td>
<td>1</td>
<td>April (3)</td>
<td>8:18</td>
<td>G</td>
<td>sperm- brown cloud; eggs-white</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>May (4)</td>
<td>9:00pm</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><em>Porites</em> sp.1 (massive)</td>
<td>3</td>
<td>April (4)</td>
<td>8:34-9:03</td>
<td>G</td>
<td>sperm- brown cloud; eggs-pale pink</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>May (4)</td>
<td>8:53</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><em>Porites</em> sp.2 (massive)</td>
<td>3</td>
<td>April (3,4)</td>
<td>8:56-9:12</td>
<td>G</td>
<td>sperm- brown cloud; eggs-pale pink</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>May (4)</td>
<td>8:53</td>
<td>G</td>
<td></td>
</tr>
<tr>
<td><em>Porites</em> sp.3 (submassive)</td>
<td>4</td>
<td>May (2,3)</td>
<td>7:50-8:05</td>
<td>G</td>
<td>sperm- brown cloud; eggs-tan</td>
</tr>
</tbody>
</table>
Gamete release was observed from 6:20 to 9:20 pm. Fourteen species were recorded to spawn in April while 36 species released gametes in May. Two years of sampling in May compared to one year in April accounts for the difference in number of scored species for the two months. In both months, a significant gamete slick was visible on the waters surface. With the exception of two *Leptastrea* species, all species that spawned in April did so again in May. Split spawning was observed for individual colonies. For instance, an individual colony of *Goniastrea aspera*, *Pectinia alciornis*, *Merulina ampliata* and *Echinipora lamellosa* were observed to spawn in April and again in May. The proportion of individual colonies participating in spawning in both months remains to be determined. The pattern of reproduction for coral populations at this site is one of a split spawning over two months with high degree of synchrony.

In April 2002, synchronous mass spawning was observed on the 3rd night following full moon although no data was recorded. Again in May 2002, April 2003, and May 2003 multi-specific spawning occurred. With the exception of 2 species, all species spawning in the 2002 mass spawning event were recorded again in 2003. A tagged colony of *Goniastrea aspera* and *Pachyseris speciosa* released gametes in May 2002 and then again in May 2003. *Merulina ampliata*, *Pectinia alciornis*, and *Pachyseris speciosa* were the only species observed to spawn in June. This could be a result of delayed spawning for these colonies. Otherwise, these 39 species were not seen to reproduce again outside of the April/May breeding period. These observations suggest that there is reproductive seasonality for this coral community and it consistently occurred in April/May for two consecutive years.

Limited data reveal that timing of spawning activity at the two sites were consistent (Table 4). For example, 3 colonies at Site #1 and 7 colonies at Site #2 of *Porites cylindrica* were documented to spawn on the third evening after the April full moon at 8:00pm. Also, a single colony of *Porites* sp.2 at Site #1 and 6 colonies of *Porites* sp. 2 at Site #2 spawned on this same evening at 9:00pm. Data from other locations and reef habitats in Palau need to be collected to verify if timing of reproduction for these 74 species is consistent.

### Table 4. Comparison of spawning times at the two sites.  
*n* = number of colonies observed to spawn. Number in parenthesis is the night after full moon when spawning was observed.

<table>
<thead>
<tr>
<th>Species</th>
<th>n</th>
<th>Location</th>
<th>Month</th>
<th>Time (pm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Porites cylindrica</em></td>
<td>3</td>
<td>Site #1</td>
<td>April 2003 (3)</td>
<td>8:00-8:05</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Site #2</td>
<td>April 2003 (3)</td>
<td>8:05-8:25</td>
</tr>
<tr>
<td><em>Porites</em> sp.2 (massive)</td>
<td>1</td>
<td>Site #1</td>
<td>April 2003 (3)</td>
<td>8:56</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Site #2</td>
<td>April 2003 (3)</td>
<td>9:00-9:09</td>
</tr>
</tbody>
</table>

A general trend of separation in timing of spawning activity was observed on evenings when multi-species spawning occurred (Figure 1). *Lobophyllia* spp. and *Pachyseris* spp. were the first to begin gamete release followed by *Merulina ampliata*, *Platygyra pini*, and *Favia* spp. With the exception of 3 genera (*Favia*, *Platygyra*, and *Leptastrea*), all other faviids released gametes next during the peak period of the evening between 7:30pm and 9:00pm. *Pectinidae* corals also spawned during the most active part of the evening.
Figure 1. Schematic representation of timing of spawning during a mass spawning evening. In general, genus are listed in order of timing of spawning activity. Pectiniidae is shown as a family as the trend is consistent for all genera within the family. Faviidae with the exceptions of the 3 listed genera also exhibits a consistent family pattern. Porites is broken into species groups to reflect the two distinct periods of spawning. Similarly, Fungia is listed out of sequence to highlight the two distinct patterns within the fungiid family.

Four species of Porites, one species of Ctenactis, and one species of Sandololitha spawned towards the end of the high activity period. Leptastrea was the last spawner for the evening. Within the genera Porites, there was a distinct separation in timing of spawning. Two species spawned during time of peak activity while 4 other species spawned towards the end of the evening. This pattern was also noticeable for within the Fungiidae family. For example, Fungia began gamete release over an hour before Ctenactis and Sandololitha.

Individual colonies were observed to spawn over several consecutive evenings. A tagged colony of
Goniastrea reitiformis, Favites halicora, Montastrea magnistellata, and Pachyseris foliosa released gametes on the third and fourth evening after the May full moon. We observed in several instances with massive faviids that when a part of a colony had been chiseled off, the remaining portion of the colony still spawned that same evening. Merulina ampliata exhibited the greatest reproductive activity with spawning between 2-6 nights following full moon in April, May and June. M. ampliata can potentially be used as the indicator species for when a mass spawning event will occur.

In the present study we were able to document reproductive timing for 74 species of scleractinian coral. 334 colonies were observed to spawn during 71 evenings of monitoring. Synchronous spawning by 10 or more species was observed to occur in March, April, May, and September (Figure 2). Non-acroporid species exhibited a marked seasonality in reproduction and tight synchrony in gamete release.

![Figure 2](image-url)  
**Figure 2.** Reproductive season for coral species in Palau from data collected for 2002 and 2003.

The evidence for Acroporidae suggests an extensive breeding season that culminates in two synchronous spawning events. Baird et al. (2000) found an extended reproductive season for Acropora in the Solomon Islands as well. However, biannual mass spawning has only been documented for Palau (Penland et al 2004). Data for October through January still needs to be collected to establish a final pattern of reproductive behavior for coral communities in Palau. The results of the current study indicate a difference in reproductive strategy of Acroporidae versus other coral families. In determining annual reproductive patterns for a region, it becomes clear that trends for one family cannot be used to reflect the entire coral population.
ACKNOWLEDGEMENTS

The authors are grateful to Dr. Robert van Woesik for coral identification. We wish to thank Ron Leidich and Teri Brugh for assistance in the field. This study was partially funded by a grant from the Nagao Natural Environmental Foundation and JICA.

REFERENCES


Kawaguti S (1944) On the physiology of corals. VI. Study of the pigments. Palao Tropical Biological Station Studies 2: 616-673


Predicting coral spawning

Robert Van Woesik
Department of Biological Sciences, Florida Institute of Technology, 150 West University Boulevard, Melbourne, Florida 32901-6988, USA    Email: rvw@fit.edu

ABSTRACT

Synchronous coral spawning is thought to be strongly related to high seasonal sea water temperatures; yet corals also mass spawn in the tropics, where sea water temperatures vary little throughout the year. Indeed, sea water temperatures are poor predictors of coral spawning in the tropics. My research has shown that cycles of solar insolation (which is the electromagnetic energy incident on the surface of the earth) coincide with coral reproductive cycles for the entire western Pacific Ocean, and should be considered as one of the primary variables driving coral reproductive cycles. Indeed, recent research in Palau (by L. Penland and colleagues) shows that coral spawning coincides with the rise toward and fall from solar insolation maxima. Two insolation maxima (a consequence of the vernal and autumnal equinoxes) in the tropics lead to multiple spawning events per year. Multiple spawning events increase the rate of genetic recombination, which in turn may facilitate the likelihood of speciation and explain, in part, the high coral diversity in the tropics.
ABSTRACT

Investigations of water temperature, geomorphology, species diversity and marine community composition were undertaken on the reef slope of Palau, western Caroline Islands, at depths of 60-360 m using mixed-gas diving and a research submersible. This research was undertaken as part of a study concerned with biodiscovery of new anti-cancer natural products for the US National Cancer Institute, and as baseline environmental data for coral bleaching monitoring.

Water temperatures in this region are extremely dynamic on both a daily and seasonal basis. Water temperatures at 90 m can change as much as 10 deg C. in 1-2 hours as a result of dynamic movement of the thermoclines. While not true internal waves, the temperatures shifts are associated with various physical phenomena presently under further investigation. The largest "internal waves" in the world, around 200 m in height, have now been documented from Palau. The depth of thermoclines in Palau also changed significantly over the course of 3-5 years and appear to be correlated with El Nino/La Nina cycles. Over 15 months, mean weekly water temperatures at 90 m decreased 9 degrees C in 2001-2002 in response to the last moderate El Nino.

Geomorphology on the reef slope consists of several zones with distinct geologic features and fauna. A break in the steep reef slope at 75-90 m occurs with a vertical to overhanging reef escarpment from that depth to about 120 m ("deep reef wall"). From 120 to about 150 m a very steep (75 deg) limestone rock face occurs dominated by shallow pitting of unknown origin on its surface ("the pitted rock face"). Below 120 m a steep (45 deg) limestone and sediment covered slope with abundant talus blocks occurs to about 200-240 m (the talus slope). Below 250 m the slope reduces and is more dominated by sediment with swales and ridges of talus blocks running downslope (swale and ridge slope). Below 300 m the slope (25-30 deg) is nearly all sediment with only occasional pieces of hard substratum (lower sediment slope).

Significant hermatypic reef corals stop at about 60-65 m depth. Between 60 and 100 m depths the fauna is not dramatically different from shallower areas of the reef slope, but below 105 m the species present change significantly. The deep reef wall (90-120 m) is dominated by lithistid sponges, gorgonians and ahermatypic corals. The pitted rock face (120-150 m) is home to relatively few benthic invertebrates, but is the shallowest area where primnoid gorgonians occur. The talus slope (150-240 m) has unique invertebrates growing on talus boulders, and spotty communities of sea pens and other invertebrates on sandy areas. The swales and ridge slope zone (250-300 m) has benthic invertebrates attached to boulders, with sea cucumbers and other sediment dwelling fauna present. The lower slope (below 300 m) is dominated by sea stars and a few other sediment inhabiting species.

Many new and poorly known taxa were seen and collected during this project and examples of these will be shown. New taxa include the first marine organism named for a Palauan individual (name presently in press). Video footage of the various environments will also be shown.
Oral Presentation Session 3
(Friday July 25, 2003)

Reef Management Issues

Chair: Alma Ridep-Morris
INTRODUCTION

In 1995 the International Coral Reef Initiative produced a Call to Action to halt and reverse the degradation of the world’s coral reefs (ICRI, 1995). That Call was accompanied by a document with guidelines as to how to approach those tasks – the Framework for Action (ICRI, 1995). Those documents have set a direction that has encouraged and funded a wide range of activities to address the tasks of halting and reversing the degradation of coral reefs and related ecosystems. That we are meeting here in this way is a clear outcome of ICRI. One of activities has included the establishment of the Palau International Coral Reef Center (PICRC). Others, such as US government support through the National Fish and Wildlife Foundation Grants scheme have provided funding for research, education and management support activities. These have assisted the work of PICRC, the Palau Conservation Society, the Coral Reef Research Foundation, The Nature Conservancy in Palau and many others in Micronesia, in the Pacific, and globally.

ICRI itself arose because of concern by Small Island Developing States and some donor nations following the World Environment Summit in Rio de Janeiro in 1992 that the issues of marine environment and natural resource management had not been adequately addressed. That this should be the case in 1992, particularly for coral reefs, illustrates the problem of getting information across the divide between science and those who make decisions in society. The quadrennial International Coral Reef Symposia started in 1962 and from the first there were papers identifying and quantifying threats, impacts and increasingly the mechanisms of those impacts on coral reefs from overfishing, destructive fishing many forms of pollution and other environmental abuse.

Those of us involved in the first 2 decades of those Symposia expected provided we identified and quantified the problems, the impacts, the likely consequences and, possible solutions, decision-makers would respond with good management decisions. By the early 1990s it was clear that very few countries had responded – the usual response was that the issues were important, that senior people acknowledged that their reefs or their fishing were probably declining but by words or actions demonstrated that it was not a priority issue. The response of the technical specialists was to condemn the lack of political will. But it is reasonable to argue that, at least in part, the lack of political will reflects a failure to communicate the significance or urgency of the results of the science in ways that prompt people to see the issues as important.

Whatever the merits of that claim, in the case of a coral reefs, a meeting of scientists in Miami in 1992 led to reports on the status of coral reefs in many countries. These were discussed at a special workshop at the 8th International Coral Reef Symposium in 1996 (Lessios, H.A. and McIntyre, I.E. 1997) and the papers presented at that workshop were summarised and updated in the first report on the status of coral reefs of the world (Wilkinson, 1998). The 1992 Miami meeting also triggered a clear expression of political will by the 8 countries that established the International Coral Reef Initiative in 1994 – Australia, France, Jamaica, Japan, Philippines, Sweden, United Kingdom and United States of America.
Without widespread acceptance that issues are important, most societies will not commit the energy and resources need to address them. This makes marine advocacy particularly problematic because most of the ecological processes of marine environmental systems are unseen below the surface and indeed effectively invisible without microscopes and other equipment. Even people who depend on the resources and wellbeing of those environments for have little understanding of how those systems operate, how human behaviour affects them and how protection and sustainable management of marine biological diversity and ecosystem processes relates to their livelihood and well-being. (Kenchington, 2003). The same can be true on land but there untrained people can see for themselves and form their own views. In the sea scientists are typically the first to identify the need and make the case for scientifically-based management to sustain marine biological diversity and ecosystem processes.

But the progress from identifying the need to implementing effective management is often marred by a continuing difficulty in negotiating or “selling” the importance and relevance of scientific information “products” in the context of the tasks, timelines, resourcing and competitive marketability of the “client” decision-maker or management agency.

**THE NATURE OF ENVIRONMENT MANAGEMENT INFORMATION NEEDS**

We do not manage environments. We can seek to manage human behaviours. We may seek to maintain biological diversity and ecological processes. For the most part we do this by encouraging and reinforcing behaviour patterns that are consistent with those goals and discouraging or banning those that are not consistent. To do this we need good information that can be used to persuade affected people and decision-makers of the need for the changes and the consequences of failing to act. In the circumstance of obscured and microscopic components that people cannot see for themselves the role of science in getting and presenting that information is critical. It is also critical that decision-makers and people affected by decisions have confidence in the processes of identifying needs and providing trustworthy information.

**INFORMATION NEEDS IN THE MANAGEMENT PROCESS**

There are three reasonably distinct phases in the information needs for management;

1. **The Campaign Phase -Making the case for management**

   This will generally involve information describing and analysing:
   
   - the importance of the biological diversity
   - the importance of the ecological processes
   - any human uses that are based upon the natural resources of the area
   - natural dynamics and impacts that underlie the resilience of the area
   - any human impacts within and beyond the boundaries that affect, threaten or are likely to threaten the area

   The clients for this information are the people who will benefit from management and those who need to be persuaded to change or limit behaviours in order to protect important areas and resources and remove threats or reduce them to levels that are sustainable. The role of the scientist as expert reporter is to build the information base and draw upon it to explain the significance of the information and the implications of failure to take action. This may overlap and even occasionally conflict with the role of
the scientist as advocate seeking to build a climate of opinion that creates the political will to take the necessary action.

2. The Planning Phase - Designing the management regime

Where the information does not exist from the campaign phase requirements typically include:

- baseline information describing the area, its resources and the socio-economic benefits, costs and functions in map and other formats
- information to identify the current degree of impact or threat of significant human activities
- information on ways to reduce the impacts or threats of use
- information on levels of impact or threat that may reasonably be expected to be sustainable in the long term
- information to support planners identifying purposes and conditions of sustainable use or entry for the managed areas

The clients for this information are planners, statutory decision-makers and all the people who will be affected by change or required to limit behaviours in order to protect important areas and resources. Typically the level of local detail required is finer than that required to make the case for management. Planning generally involves choices among options for specific areas to be allocated to particular levels or types of use. It is usually important to understand the implications of the alternatives. At the fine scale it is important that there is an informed and systematic choice so that the process is seen to be reasonable in addressing the consequences for those disadvantaged by management measures.

3. The implementation Phase

The ongoing role of science in management is to provide objective information on:

- performance of management in implementation of the plan
  - in achieving environmental and natural resource management objectives
  - in implementing and enforcing regulations.
- changed circumstances because of better or more recent scientific information
- changed attitudes towards management
- new approaches to management

Here the immediate client is likely to be the management agency. Increasingly in the context of program budgetting, performance information is likely to be required for financial and outcome reporting to Parliaments or other funding bodies. Further, where a developing nation is party to multilateral environment agreements there are defined requirements for scientific information in regular reports on progress and performance in addressing the objectives. Those reports may be significant factors in securing ongoing international funding to support management related to the agreement in question.

Here the context is to assess whether management is achieving its objective and whether it is efficient in terms of use of financial and other resources. The information from the implementation phase provides the basis for review and for changes to reflect new information, the experience of management and changes in community attitudes resulting from that experience.
WHY IS A CLIENT FOCUS IMPORTANT?

It can be argued that the context of science has changed substantially in recent decades.

In the mid-20\textsuperscript{th} century science was seen as a “good thing” and the “dotty professor” an affectionate figure of fun, humanising a remote authority figure. There were few people in public life with scientific training but support of scientific research was accepted as a core society and government function that would underpin future benefits. The scientific institutions were relatively unchallenged in setting their programs.

By the end of the 20th century there was more ambivalence in the face of the impacts of technologies that sprang from science and the “dotty professor” had evolved into the “mad professor” and become a sinister figure cooking up genetic freaks, nuclear horrors and worse. There were increasing numbers of scientifically trained people in public life. There was a more critical approach to government support of scientific research and a view that where industry benefitted it should pay for the research. Governments generally accepted the need to support research but increasingly required that it address clear objectives relating to government programs and priorities. In most countries research now has to compete harder and with a broader range of policy alternatives such as health, education and environment management for its share in a government budget.

Under these circumstances we have to be better prepared to “sell” the science product to the government or funding agency. We have to make clearer cases in terms that reach beyond the comfortable club of science if we want support for research to understand energy flows in ecosystems, to describe ecological communities and their dynamics or to monitor the environment. We have a particular problem with coral reef research because to many people the fieldwork looks like a fun recreational activity. Indeed we often find it hard to get Ministers or senior officials to inspect our work in the field for fear that a press photograph will make it appear that they are on a junket.

HOW DO WE APPROACH CLIENT FOCUS?

1. Identify the client/s

That is often the agency paying for the research. But in some grant of foundation systems the payer may be buying information for a third party such as a developing country government agency or NGO in which case there may be 2 or more clients.

2. Understand the objectives of the client

Some government and foundation programs that are concerned solely with supporting excellence in research as identified and evaluated through the institutions of science with no immediate applied objective.

Most government and international programs tend to allocate funding in relation to immediate or close functional objectives that support the development of policy or the implementation and evaluation of programs.

Some private sector funding is linked to social dividend outcomes. For example being seen to support coral reefs may help position the client as socially responsible and perhaps help with logo or brand.
recognition in a market place not immediately connected with the research area. Most private sector funding is usually tightly linked to specific commercial outcomes.

Large foundations tend to have clear objectives and guidelines and to be supported by expert staff and advisory groups of a scale and spread of expertise similar to those of governments and international agencies. The philanthropic objectives of most foundations relate to specific areas of outcome for the good of humanity typically defined by the primary donor when establishing the foundation, but some have more freedom to allocate funding on the basis of excellence and innovation.

Objectives can be met without compromising the principles of good science but it is the ethical responsibility of the scientist as provider to design good science and demonstrate the relevance of the good science in terms that relate to the objectives of the client.

3. Reward the client

Clients generally decide to fund or support proposals in a competitive context where there are several options for allocating the available funding. Their decisions are justified and reinforced by good, timely reports.

To the extent that the research relates to functional objectives it is important to deliver against those objectives and to report in clear non-technical terms how the results of the research advance or relate to those objectives. That can demystify the business of science and build client confidence in the scientific process.

In the case of governments, where the significance or usefulness of the results are communicated effectively to the public, the client is justified in supporting the research in the face of competing bids for public expenditure. Further, to the extent that aspects of the functional research can also be published in peer-reviewed scientific journals the client can be further rewarded by a broader recognition of the quality of the science used to address that functional objective.

To the extent that support of research relates to social dividends or to more precise philanthropic or scientific objectives it is important to reward the client with good publicly accessible science, comprehensible information and clear recognition of the value of the support provided.

CONCLUSION

The information flowing from coral reef science is a commodity that may be valued for its existence but it should be valued for its relevance in understanding or solving problems relating to the interactions between people and reefs. But the history and practise of marine science has perhaps focused on the existence value of the information for the scientific community rather than client or public relevance. An overt consideration of the perspectives and needs of clients for coral reef research information may help to build a more secure basis for research programs and centers.
REFERENCES


ABSTRACT

In 2002, The Environment, Inc. was commissioned by the Office of Environmental Response and Coordination to conduct a comprehensive analysis of resource use in Palau as part of the National Biodiversity Strategic Action Plan (NBSAP) for the Convention on Biological Diversity. The analysis included input from 35 key informants in the government and non-government sector. In addition, a nation-wide community based survey of over 357 people was conducted by Palau Conservation Society as part of the NBSAP process and incorporated into this study.

The informants and the community perceived that terrestrial resources managed through traditional agroforestry were being used sustainably and had high potential. Threats to agroforestry were associated with Climate Change and included droughts, fires, increased incidence of pests- like the introduced fruit flies and market fluctuations. Marine and terrestrial resources within managed areas such as preserves, habitats of endangered species, spawning aggregations and areas with restricted use were perceived as being used sustainably. Selected fisheries resources perceived as being used sustainably included offshore tuna, pelagic fish, medium sized parrotfish, surgeonfish and trochus.

The informants and the community perceived that most inshore fisheries resources were not being used sustainably. These resources included most reef fish, humphead wrasse, bumphead parrotfish, giant clam, sea urchins, sea cucumbers and crab. The informants and the community perceived that unsustainable activities impacting resources included dredging, filling of mangroves, over harvesting of marine organisms, deforestation, fires, quarrying and unplanned development. Sea level rise and global warming were perceived as a threat to shorelines, taro crops and the reefs especially in the low-lying outer States.

Most informants perceived that all resources could be used sustainably that currently were not and that there was potential for agroforestry and aquaculture of clam, sponges, rabbitfish and crabs. Potential production of salt, phosphate and bauxite were suggested during community consultations. Some informants perceived that benefits were being reinvested in the management of resources through government programs such as the financial returns from the tuna fishery, State clam aquaculture programs, the national surveillance program, and the Rock Island Permit System of Koror State. Most informants believed these programs were not enough and that little or no benefits were being reinvested into the management of most resources.

The informants believed that the key beneficiaries were the local residents including fishermen, farmers, businessmen, women and the youth. Some informants believed that foreign investors and businessmen benefited the most. The informants stated that the best ways to promote sustainable development were through capacity building including education, public awareness and technical training, information collection and sharing, coordinated efforts, mutual support at all levels, funding existing programs, a personal sense of responsibility and a change in attitude.

Based upon the literature review and information collected from various agencies, there was insufficient information or gaps in our knowledge in the following areas: 1) sustainable harvest
levels of key marine species, 2) population size and distribution of endangered or threatened species, 3) financial benefits from fisheries and tourism, 4) informal or non-commercial inshore fisheries production, 5) land use changes over time, 6) point sources of pollution and measurable impacts of pollution, 7) land use planning, and 8) potential production and markets for cultured marine and terrestrial products.

Future work or programs needed to fill these gaps includes the following: 1) capacity building through training, public awareness and education, 2) the development of databases and websites, 3) the development of regulations that require collection and deposition of information about resource use, 4) an effective financial program that ensures that benefits from resource use are being reinvested into the management of those resources, 5) periodic comprehensive surveys of resources and 6) a comprehensive waste management program.
The importance of incorporating public values in coastal management: 
A case study on public preferences for coastal resource use and attitudes towards marine protected areas in Palau

Shannon Long
School for Resources and Environmental Studies, Dalhousie University
1312 Robie St., Halifax, NS B3H3E2, Canada   Email: slong@dal.ca

EXTENDED ABSTRACT

This research was conducted under the Marine Protected Area Management Effectiveness Initiative for the Pacific Islands as thesis research for a Master’s degree in environmental studies from Dalhousie University, Nova Scotia, Canada.

In an attempt to manage the multiple uses of coastal zones, many places have adopted different types of management plans. In order for any management plan to be successful, it must include the values and opinions of all those involved and affected by the coastal zone in question. Managers must be provided with information on different stakeholder values and preferences in order to make decisions that incorporate everyone’s input. A stakeholder is any individual or group that has a vested interest in the coastal zone, and can include residents, tourists, fisherpersons, biologists, environmentalists, businesses, and government among others.

Marine Protected Areas (MPAs) have been created around the world as part of coastal conservation efforts. An MPA is an area of the coastal zone that has been designated by the government for some degree of protection. They are an important part of coral reef conservation because they help to manage activities in sensitive areas. MPAs must be evaluated to measure their success - this includes studying the management of MPAs.

The Marine Protected Area Management Effectiveness Initiative is an international effort headed by:

- World Commission on Protected Areas (WCPA),
- World Wildlife Fund (WWF),
- National Oceanic and Atmospheric Administration (NOAA), and
- David and Lucille Packard Foundation.

The goal of this project is to develop and implement guidelines for evaluating the management effectiveness of MPAs, and to field-test this effectiveness through pilot studies. The management effectiveness of an MPA can be defined as, “the degree to which a protected area is used to achieve its goals and objectives” (WCPA-Marine/WWF 2002).

The project involves indicator development in three different areas: governance, biological, and socio-economic. My research focuses on one of the socio-economic indicators: people’s attitudes and beliefs for coastal resources and marine protected areas. I chose to design and test my survey in Palau, one of the project’s pilot sites in the South Pacific.

It is extremely difficult to measure people’s values, especially values for goods and services that are not commonly priced. There are many different types of values, adding up to what economists call ‘total economic value’. These values are categorized into use and non-use values, as depicted in the following diagram.
People have use value for goods or services that they ‘use’ in order to receive the benefits. Market use is the value people gain from a commodity, such as driving a car or eating an ice cream cone. Non-market use describes the values people receive from non-market ‘goods’, such as viewing a beautiful sunrise, or having greenspace in their community. Non-market goods do not have monetary value, and are therefore not included in traditional economic analysis. People have non-use values for goods or services that they care about even if they don’t use or consume them themselves. Bequest value is the value that people place on conserving goods and services for future generations. Option value is the value people have for knowing that they have the option to benefit from something, such as knowing that they could go snorkeling and see large sea turtles. Existence value is the benefit a person receives from just knowing that an ecosystem, species, nice view, etc. exists and is being protected so that it will continue to exist.

A survey was designed in order to gain a better understanding of these different types of values held by the public with respect to the coastal zone, as well as to explore their attitudes on MPAs. This survey was designed to get at the tradeoffs people make with respect to the different possible uses of their coastal zone. In addition, the survey seeks to gain knowledge of people’s perceptions of the marine protected areas that currently exist in Palau.

The survey was given to a 5% sample of Koror State, based on the number of households from 2000 Census data. A total of 115 surveys were carried out in person by the researcher, with the assistance of a Palauan student.

The first section of the survey was designed using conjoint valuation analysis software. It is a paired comparison survey consisting of 12 questions, and asks respondents to choose between two different possible future scenarios for Palau. Each question involves 5 different considerations: condition of the fisheries, tourism development, culture, condition of the coastal zone, and annual personal income. Respondents choose whether they strongly, somewhat, or slightly prefer Future A or B, or if they have no preference between the two options.

The second section of the survey is an opinion survey that uses ratings. People were asked 10 questions about MPAs, 2 questions for each of the five considerations mentioned above. Respondents answer on a scale from 1 to 5 whether they strongly or somewhat agree or disagree with the statement,
or if they have no opinion.

It is expected that the results from this survey can be used to develop an indicator that could be applied to Palau and many other countries, in the Pacific and elsewhere. This indicator could contribute to the ability to assess the management effectiveness of MPAs, as well as a method for gaining public input into coastal zone management issues. This information is important for managers if they are to make decisions in consideration of the public.

Hopefully the results of this research will be used by coastal managers and government leaders in Palau, and could lead to improved decision-making that considers public wants and values. This way, decisions that affect the future of Palau’s coastal ecosystem could potentially be made with an awareness of what Palauans want and value in terms of coastal resources and activities.

REFERENCES


Palau’s Nationwide Protected Areas Network: Applying Innovative Ideas for Coral Reef Conservation

Andrew Smith
Director, Pacific Island Countries Coastal Marine Program,
The Nature Conservancy
P.O. Box 1738, Koror, PW 96940, Republic of Palau
Tel: +680 488 2017  Fax: +680 488 4550  Email: andrew_smith@tnc.org

ABSTRACT

The Republic of Palau has initiated the establishment of a Nationwide Network of Protected Areas. To that end, the Palau National Congress (Sixth Olbiil Era Kelulau) is considering “The Protected Areas Network Act”. The purpose of the Act is to establish a nationwide network of protected areas that will allow the national government to assist states in the protection of areas of significant biodiversity, important habitats, and other valuable resources that are essential to the future stability and health of Palau. The network has the dual purpose of protecting Palau’s unique biodiversity and supporting the states and communities to effectively manage and protect their natural resources.

The Nature Conservancy has a special interest in supporting the establishment of the network, with an initial focus on the establishment of a nationwide network of marine protected areas. Globally, the Conservancy is leading a highly collaborative program to transform the way coral reef related marine protected areas (MPAs) are selected, designed and managed. The goal of this program is to catalyze a worldwide effort to establish networks of inter-connected MPAs within high biodiversity tropical marine ecoregions that are designed to survive and managed to last.

Coral reef conservation must effectively address local needs and threats, their underlying causes and build resilience in the face of large-scale, unmanageable global threats to biodiversity, such as coral bleaching. Building on traditional and legislative protection already in place, the establishment of the marine component of Palau’s protected areas network will be the first application of these new ideas for coral reef conservation – resilience, survivability, connectivity and financial sustainability. The five core principles that are being applied in Palau include:

- Establishing MPAs and integrating them into a wider management framework.
- Building resilience in the face of change into MPA networks for the long-term survival of coral reefs and related biodiversity.
- Developing sustainable means for MPAs to meet their costs.
- Strengthening local capacity to manage MPAs effectively.
- Establishing supportive policies to provide incentives for conservation and the sustainable use of marine resources, and the integration of conservation into development priorities.

This presentation will outline the background to the development of the proposed Protected Areas Network, the innovative concepts underpinning the transformation of coral reef conservation, and how Palau is leading the world in applying those concepts to the design of its marine protected areas network.
PRESENTATION SUMMARY

This presentation will address the following:

- Protected Areas Network
  - What is it?
  - Why is it needed?
- Transforming coral reef conservation:
  - MPA design
  - Resilience, survivability, connectivity and financial sustainability
- Science needs:
  - The challenge to you!

Nationwide Protected Areas Network

- The Nationwide Protected Areas Network will have dual purposes:
  - The protection of biodiversity, habitats and valuable natural resources Palau-wide, and
  - Addressing local resource management needs
- The network will include both marine and terrestrial areas
- The full range of protected area options will be applied as appropriate, from total closure through to use restrictions. The IUCN protected areas categories will be used as a guide
- Full use will be made of the latest design criteria and protected area science
- The network will build on existing initiatives and protected areas (see Figure 1)

Figure 1. Palau’s Existing Protected Areas
• It will require working closely with States and communities
• Virtually all of Palau’s current protected areas have been established for local resource management purposes
• Collectively they do form an ad hoc system of protected areas, but national-level biodiversity or habitat protection were never intended objectives of these areas

Protected Areas Network (PAN) Act

• The drafting of the PAN Bill was a collaborative effort of all the main environmental groups over a six month period
• The PAN Act will establish a national framework to support state-level action
• The Protected Areas Network will NOT be a “National Parks System” controlled by the national government, but rather a state-based system supported by the national government, reflected by the dual objectives noted before

The Current Status of the PAN Act

• 6th Olbiil Era Kelulau (6th Palau National Congress):
  □ The bill has been passed by the House of Delegates
  □ Currently under consideration by Senate
• As the PAN Act is a new approach to protected areas management for Palau it has required some explaining to ensure that the leaders fully understand its purposes
• Once the Act comes into force, the Ministry of Resources and Development will be responsible for its implementation
• The Nature Conservancy will provide the initial funding and technical support, through a Memorandum of Understanding with the Ministry, to ensure the PAN Act can be promptly implemented
• Initial focus will be on marine protected areas, as this is an area where considerable work has already been undertaken in Palau

Why is the PAN a TNC Priority?

• The Conservancy is leading a highly collaborative effort to transform coral reef conservation (TCRC program)
• The goal is to catalyze the worldwide establishment of representative, mutually-replenishing networks of MPAs in priority areas
• TNC recognizes that these networks must address local management needs and threats, as well as build resilience to large-scale, unmanageable global threats such as coral bleaching, diseases, and so on

Why Focus on Palau?

• A number of expert design teams have identified Palau as priority area for first application of these innovative concepts
• There is strong political and government support for conservation and protected areas
• Palau has a very long history of innovative action on resource management, conservation, and the establishment of MPAs, going right back to traditional management systems
• All the major tropical marine systems are present in Palau
• There are excellent research facilities within the country
**What’s Different?**

- The TCRC program builds on existing MPA design criteria, it doesn’t replace them
- It incorporates the ideas of resilience, replication, survivability, connectivity, and refugia to address global threats. Figure 2 shows the developing resilience model.
- The aim is to establish representative, mutually-replenishing networks of MPAs to enhance recovery prospects after the impacts of global events (e.g. coral bleaching)
- The major components include:
  - Incorporating MPAs into wider management frameworks
  - Developing financial sustainability
  - Strengthen local management capacity
  - Establish supporting policies: incentives, “mainstreaming” protected areas and conservation into both government and development processes
  - Effective science

---

**Figure 2. The Developing Resilience Model**

**Science**

The initial priorities for the science component are:

- Identifying areas that are of the highest priority for MPA networks (this will be at varying scales from national through to global)
Focusing first on coral reef systems then expand to other ecosystems
An initial emphasis on coral bleaching resistance, spawning aggregations, connectivity, after which there will be an expansion to other global threats, such as diseases, marine invasive species, etc.
Modifying MPA design criteria

Current Research and Information Needs

- Coral bleaching
  - Environmental factors affecting mortality and survival
- Reef fish spawning aggregations
  - Understanding how they work
- Connectivity
  - Current regimes
  - Reef fish and coral larval dispersal and recruitment
  - Migration
- MPA design
  - Including resilience factors
  - Size, shape, location, selection
- Monitoring and evaluation protocols
  - Ecological
  - Program & management effectiveness

Conclusion

- The nationwide Protected Areas Network and the Transforming Coral Reef Conservation program will not solve all problems, but they do begin to some of the highest priority address global threats, while also recognizing the need to deal with local threats and resource management needs
- We are in the very early stages of what will be a long term effort (10+ years)
- Many related research efforts are already underway or planned for Palau, including:
  - Spawning aggregation studies by the Coral Reef Research Foundation, the Society for the Conservation of Reef Fish Aggregations, and TNC
  - Coral bleaching risk mapping and modeling by NOAA / AIMS / TNC
  - Coral reef ecosystem monitoring by PICRC
  - Ecoregional planning to identify areas of biological significance by TNC
  - The planned World Bank Targeted Research, where Palau is being proposed as one of the study sites for a number of the working groups
- Palau is proceeding based on the existing knowledge (and educated guesses!), but will apply adaptive management as new scientific results emerge
- Targeted research needed to ensure the Protected Areas Network is based on the best science available… and it is up to people like you to undertake that research!!

A final point…

- In Palau, we have all been extremely poor at communicating our priorities, needs, activities, and results, within and between the researchers, managers, and policy makers
- To that end we need more, and more effective: Communication, communication, communication

Thank you.
Poster Presentation Session

(Thursday July 24, 2003)

Research on Reefs and Resources

(Abstracts only)

Chair: Ken Okaji
A comparative study of adductors of a gastropoda and a bivalvia, *Julia* and *Tridacna*

A. Matsuno, C. Abe and M. Imada  
Department of Biological Science, Shimane University,  
1060 Nishikawazu, Matsue, Shimane 6908540, Japan  
Email: matsuno@life.shimane-u.ac.jp

ABSTRACT

Many kinds of shellfishes live in a coral reef. Among them, *Julia* is classified into a gastropoda, but has two valves at the both sides of the body, and has an adductor to close the valves. However, the adductor contracts within a narrow range, and can not keep its contracted state for a long time. On the contrast, *Tridacna* is a bivalvia, and has a large adductor which contracts within a wide range, and can keep a contracted state for a long time. Thus, the adductor of *Tridacna* shows “catch contraction”. As the two types of adductors showed those differences, we suspected that the two adductors must have different types of muscle cells in them. Under these circumstances, we studied ultrastructures of those muscle cells, and try to clear differences between them.

As the results, an adductor of *Julia* was composed of one type of smooth muscle cells. The cells included two kinds of myofilaments; thin filament of about 7nm in diameter and thick one of about 63nm. An adductor of *Tridacna* had two parts; an opaque and a translucent. The arrangement was resembled to that of a typical clam adductor. The outer opaque portion had smooth muscle cells, and an inner translucent portion was composed of obliquely cross striated muscle cells. The opaque portion was constructed of two types of smooth muscle cells classified by diameter of their thick filaments. That is, the opaque portion of a *Tridacna* adductor was composed of smooth muscle cells having thick filaments of about 72 nm in diameter and another type of cells having filaments of about 92 nm. The latter type of cells resembled to smooth muscle cells which have been reported in many kind of clams.

We supposed that the peculiar smooth muscle cells having very thick filaments (92nm in diameter) may be the “catch muscle”, because they were not found in a *Julia* adductor which does not keep the contracted state for a long time, but observed in *Tridacna* adductors enduring the contracted state.
The distribution of pomacentrid fishes, hermatypic corals, and marine plants in the moat of Ishigaki Island, southern Japan: capability as indicator species for the evaluation of coral reef ecosystem

T. Shibuno¹, Y. Takada¹, Y. Fujioka², H. Ohba¹, K. Hashimoto¹ and O. Abe¹
¹ Ishigaki Tropical Station, Seikai National Fisheries Research Institute
148-446 Fukai-Ohta Ishigaki Okinawa 907-0451, Japan Email: shibunot@affrc.go.jp
² Fisheries Division, Japan International Research Center for Agricultural Sciences
³ Department of Aquatic Biosciences, Tokyo University of Fisheries

ABSTRACT

The fauna of pomacentrid fishes, hermatypic corals, and marine plants at 46 points on the offshore moat near reef flat, middle of the moat, and the near shore moat at 16 study area along east coast of Ishigaki Island, southern Japan was investigated by field surveys using 50m x 4m belt transect and 1m x 1m quadrat methods at the same transect on September, both 2000 and 2001.

A total 48 species of pomacentrids, 123 species of hermatypic corals, and 136 species of marine plants were recorded in the moat of the island. The number of species and individuals of pomacentrids, and the number of species and the percent cover of hermatypic corals were generally lesser in the near shore moat than the offshore and middle of the moat. Multivariate analyses were carried out to detect indicator species and environmental gradients by using presence-absence data of 296 species (38 species of pomacentrids, 122 species of hermatypic corals, and 136 species of marine plants). Cluster analyses revealed five major clusters depending on the variation of species composition and a subsequent analysis (IndVal) detected indicator species of respective clusters.
The role of aquarium on the coral reef conservation

Masanori Nonaka* and Hiromi Yamamoto
Okinawa Churaumi Aquarium, 424 Ishikawa, Motobu-cho, Okinawa 905-0206, Japan
* Email: m_nonaka@kaiyouhaku.or.jp

ABSTRACT

Okinawa Churaumi Aquarium was opened on November 1, 2002, for the purpose of introducing marine organisms in the waters of Okinawa, Southern Japan. There are three major exhibitions in the aquarium: Coral reef zone, Kuroshio Current zone and Deep-sea zone. For the establishment of coral reef zone, we have been making a series of ecological and behavioral studies on hermatypic corals and reef organisms using experimental aquaria since 1994. Growth rates and survivorships of corals were measured under various environmental conditions such as depth and current speed. The results from experimental aquaria were applied to an exhibition layout of live corals in a 300 tons tank.

Acroporid and Pocilloporid corals are successfully propagated in the experimental aquaria. Twenty four small pieces of Acopora nobilis, A. muricata and A. microphthalma were grown out to approximately 100 big colonies in eight years. These colonies reached sexual maturity and started spawning in 1996. They kept spawning every year, around full moon in June, even though they were affected by the 1988 mass-bleaching event. Their gametes and embryogenesis appeared quite normal.

We, as the only aquarium in Okinawa Island, are trying to contribute toward conservation of Okinawan coral reefs that have been heavily devastated from the 1998 mass-bleaching event and consequent Crown-of-Thorns Starfish outbreaks. There are two directions: one is reef rehabilitation by using transplants and spats propagated in our aquarium and the other is educational activities such as “watching of coral spawning” excursion, lecture series of coral reef ecosystem and logistic support of coral reef studies for visiting researchers.
Development of immuno-identification technique for the larvae of the Crown-of-Thorns Starfish, Acanthaster planci (L.)

K. Nadaoka¹, M. Hamaguchi², M. Sasaki², S. Harii¹, K. Okaji³ and D. Idip Jr.⁴

¹Graduate School of Information Science and Engineering, Tokyo Institute of Technology
O-okayama, Meguro-ku, Tokyo 152-8552, Japan
²Fish and Shellfish section, Research Institute of Seto Inland Sea, Fishery Research Agency
Maruishi 2-17-5, Ohno, Hiroshima 739-0452, Japan
³IMG Inc. Nurumizu 667-1, Atsugi, Kanagawa 243-0033, Japan
⁴Palau International Coral Reef Center
PO Box 7086, Koror, Palau 96940

ABSTRACT

Outbreaks of the Crown-of-Thorns Starfish, Acanthaster planci (L.), are the major management problem on coral reefs. Previous studies suggest that evaluating dispersion patterns of A. planci larvae is essential to understand mechanisms of outbreaks. Some hydrodynamic studies showed possible relationships between larval dispersion and recruitment. However, no empirical data on field distribution of A. planci larvae have been obtained. This is due to an inability in distinguishing A. planci larvae among larvae of other starfish species. A possible approach to this problem is to develop immunological probes, i.e. monoclonal antibodies, which specifically react to A. planci larvae. To achieve this objective, we produced 62 monoclonal antibodies against preserved samples of laboratory-reared A. planci larvae. Seventeen monoclonals were selected as A. planci specific through cross-screening with two different species, Linckia laevigata and Asterina pectinifera. Of the seventeen monoclonals, three showed a distinctive immunofluorescence pattern. These monoclonals reacted with some asteroid larvae that were found among wild-caught plankton samples from Palau. The results of genetic analysis strongly suggest that the larvae are those of A. planci.
<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation &amp; Email Address</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mr. John Bungitak</td>
<td>Republic of Marshall Islands <a href="mailto:eparmi@ntamar.net">eparmi@ntamar.net</a></td>
</tr>
<tr>
<td>Dr. Katherine A. Chaston</td>
<td>Management Officer, Department of Conservation and Law Enforcement, Koror State Government P.O. Box 116, Koror, Palau 96940 <a href="mailto:rica@palaunet.com">rica@palaunet.com</a></td>
</tr>
<tr>
<td>Dr. Patrick Colin</td>
<td>Director, Coral Reef Research Foundation P.O.Box 1765, Koror, Palau 96940 <a href="mailto:crrf@palaunet.com">crrf@palaunet.com</a></td>
</tr>
<tr>
<td>Ms. Lori J.B. Colin</td>
<td>Laboratory Manager, Coral Reef Research Foundation P.O.Box 1765, Koror, Palau 96940 <a href="mailto:crrf@palaunet.com">crrf@palaunet.com</a></td>
</tr>
<tr>
<td>Mr. Asher Edward</td>
<td>Federated States of Micronesia</td>
</tr>
<tr>
<td>Mr. Adalbert Eledui</td>
<td>Director, Department of Conservation and Law Enforcement, Koror State Government P.O. Box 116, Koror, Palau 96940 <a href="mailto:rorrangers@palaunet.com">rorrangers@palaunet.com</a></td>
</tr>
<tr>
<td>Ms. Carol Emaurois</td>
<td>GCRMN Node Coordinator, Palau International Coral Reef Center P.O. Box 7086, Koror, Palau 96940 <a href="mailto:cemaurois@picrc.org">cemaurois@picrc.org</a></td>
</tr>
<tr>
<td>Dr. Katharina Fabricius</td>
<td>Senior Research Scientist, Australian Institute of Marine Science PMB 3, Townsville, Queensland 4810, Australia <a href="mailto:k.fabricius@aims.gov.au">k.fabricius@aims.gov.au</a></td>
</tr>
<tr>
<td>Dr. Lee-Shing Fang</td>
<td>Director General, National Museum of Marine Biology and Aquarium 2 Houwan, Checheng, Pingtung 944, Taiwan, ROC <a href="mailto:lsfang@nmmba.gov.tw">lsfang@nmmba.gov.tw</a></td>
</tr>
<tr>
<td>Mr. Rodney J. Galama</td>
<td>Scientific Officer (Marine Ecologist), Department of Environment and Conservation P.O. Box 6601, Boroko, National Capital District, PNG <a href="mailto:rgalama@hotmail.com">rgalama@hotmail.com</a></td>
</tr>
<tr>
<td>Mr. Yimnang Golbuu</td>
<td>Chief Researcher, Palau International Coral Reef Center P.O. Box 7086, Koror, Palau 96940 <a href="mailto:ygolbuu@picrc.org">ygolbuu@picrc.org</a></td>
</tr>
<tr>
<td>Dr. Saki Harii</td>
<td>Lecturer, Department of Mechanical and Environmental Informatics Tokyo Institute of Technology 2-12-1 Otokayama, Meguro, Tokyo 152-8552, Japan <a href="mailto:harii@wv.mei.titech.ac.jp">harii@wv.mei.titech.ac.jp</a></td>
</tr>
<tr>
<td>Mr. Mike J. Hasurmai</td>
<td>Marine Specialist, Marine Resource Management Division, Department of Resources and Development P.O. Box 251, Yap, Federated States of Micronesia <a href="mailto:mrmddyap@mail.fm">mrmddyap@mail.fm</a></td>
</tr>
<tr>
<td>Dr. Thomas F. Hourigan</td>
<td>Coral Reef Coordinator, NOAA Fisheries, Office of Habitat Conservation Room 15860, SSMC-3, 1315 East-West Highway, Silver Spring, MD 20910, USA <a href="mailto:Tom.Hourigan@noaa.gov">Tom.Hourigan@noaa.gov</a></td>
</tr>
<tr>
<td>Mrs. You-chin Hsu</td>
<td></td>
</tr>
</tbody>
</table>
Mr. David Idip Jr. Researcher, Palau International Coral Reef Center
P.O. Box 7086, Koror, Palau 96940 <didip@picrc.org>

Mr. Robert Jackson Federated States of Micronesia

Dr. Yoshihisa Kamishima Professor, Department of Human Nutrition, Chugokugakuen University
83 Niwase, Okayama 701-0197, Japan <ykm@cjc.ac.jp>

Dr. Siro Kawaguti Professor Emeritus, Okayama University
1-6-20 Tshima-Fukui, Okayama 700-0080, Japan

Dr. Hajime Kayanne Associate Professor, Department of Earth and Planetary Science, University of Tokyo
Hongo, Tokyo 113-0033, Japan <kayanne@eps.s.u-tokyo.ac.jp>

Dr. Richard Kenchington Professor, Centre for Maritime Policy, University of Wollongong
NSW 2522, NSW Australia <richard.kenchington@netspeed.com.au>

Mr. Tadashi Kimura Researcher, Japan Wildlife Research Center
3-10-10 Shitaya, Taito, Tokyo 110-8676, Japan <tkimura@jwrc.or.jp>

Mrs. Ann Kitalong Biologist, The Environment, Inc.
P.O.Box 1696, Koror, Palau 96940 <kitalong@palaunet.com>

Dr. Kenji Konishi Professor Emeritus, Department of Evolution of the Global Environments, Kanazawa University
6-28-501 Tamagawa, Kanazawa, Ishikawa 920-0863, Japan <QWB02765@nifty.ne.jp>

Mrs. Hiroko Konishi

Ms. Shannon Long Student Researcher, School for Resources and Environmental Studies
Dalhousie University 1312 Robie St., Halifax, NS B3H3E2, Canada <slong@dal.ca>

Dr. Tadashi Maruyama Director, Marine Ecosystems Research Department, Japan Marine Science and Technology Center 2-15 Natsushima-cho, Yokosuka, Kanagawa 237-0061, Japan <tadashim@jamstec.go.jp>

Dr. Akira Matsuno Professor, Department of Biological Science, Shimane University
1060 Nishikawazau, Matsue, Shimane 690-8540, Japan <matsuno@life.shimane-u.ac.jp>

Mr. Francis Matsutaro CEO, Palau International Coral Reef Center
P.O. Box 7086, Koror, Palau 96940 <matsutaro.picrc@palaunet.com>

Ms. Elizabeth Matthews Marine Conservation Officer, Palau Conservation Society
P.O. Box 1811, Koror, Palau 96940 <pcs@palaunet.com>

Dr. Kazuo Nadaoka Professor, Department of Mechanical and Environmental Informatics
Tokyo Institute of Technology
2-12-1 Ouokayama, Meguro, Tokyo 152-8552, Japan <nadaoka@mei.titech.ac.jp>
Mr. Tasuku Nagasaki
Chief Aquarist, Okinawa Churaumi Aquarium
424 Ishikawa, Motobu-cho, Okinawa 905-0206, Japan
<tnagasaki@kaiyouhaku.or.jp>

Ms. Metiek K. Ngirchechol
Conservation Management Officer, Marine Conservation and Protected Areas
Program Bureau of Marine Resource <kimie@palaunet.com>
P.O. Box 359, Koror, Palau 96940

Mr. Masanori Nonaka
Aquarist, Okinawa Churaumi Aquarium
424 Ishikawa, Motobu-cho, Okinawa 905-0206, Japan
<m_nonaka@kaiyouhaku.or.jp>

Dr. Ken Okaji
Consultant, IMG Inc.
Nurumizu 667-1, Atsugi, Kanagawa 243-0033, Japan
<ken_okaji@pop06.odn.ne.jp>

Ms. Ilebrang U. Olkeriil
Rock Island Support Officer, Department of Conservation and Law
Enforcement, Koror State Government
P.O. Box 116, Koror, Palau 96940 <rica@palaunet.com>

Dr. Makoto Omori
Director, Akajima Marine Science Laboratory
179 Aka, Zamami, Okinawa 901-3311, Japan <makomori@amsl.or.jp>

Ms. Lolita Penland
Researcher, Palau International Coral Reef Center
P.O. Box 7086, Koror, Palau 96940 <lkpenland@palaunet.com>

Ms. Jolene M. Rafael
P.O. Box 1955, Koror, Palau 96940 <leejoe21@yahoo.com>

Ms. Alma Ridep-Morris
MPA Program Manager, MCPA Program, Bureau of Marine Resources
P.O. Box 359, Koror, Palau 96940 <almarm@palaunet.com>

Mr. Belhaim Sakuma
Executive Director, Palau Conservation Society
P.O. Box 1811, Koror, Palau 96940 <pcs@palaunet.com>

Mr. Dave Sapio
Peace Corps Volunteer, Palau International Coral Reef Center as at July, 2003
P.O. Box 7086, Koror, Palau 96940 <davesapio@hotmail.com>

Dr. Takuro Shibuno
Chief, Aquatic Ecology Section, Ishigaki Tropical Station,
Seikai National Fisheries Research
148-446 Fukai-ohta, Ishigaki, Okinawa 907-0451, Japan
<shibunot@affrc.go.jp>

Dr. Andrew Smith
Director, Pacific Island Countries Coastal Marine Program,
The Nature Conservancy
P.O.Box 1738, Koror, Palau 96940 <andrew_smith@tnc.org>

Dr. Nacanieli Tuivavalagi
Private Consultant, Global Consultancy Ltd.
Vaimoso, P.O.Box 1287, Apia, Samoa <filia@samoa.ws>

Mrs. Filifilia Tuivavalagi

Dr. Robert Van Woestik
Associate Professor, Department of Biological Sciences,
Florida Institute of Technology
150 West University Blvd., Melbourne, FL 329016988, USA <rvw@fit.edu>
Mr. Steven Victor  Researcher, Palau International Coral Reef Center
P.O. Box 7086, Koror, Palau 96940 <svictor@picrc.org>

Dr. Clive Wilkinson  Coordinator, Global Coral Reef Monitoring Network,
Australian Institute of Marine Science
P.O. Box 772, Townsville, Queensland 4810, Australia
<clive.wilkinson@crcref.com>

Dr. Kiyoshi Yamazato  Special Researcher, Research Institute, Meio University
2-15-1 Shuri-Tera-Cho, Naha, Okinawa 903-0806, Japan
<kamazato@msi.biglobe.ne.jp>