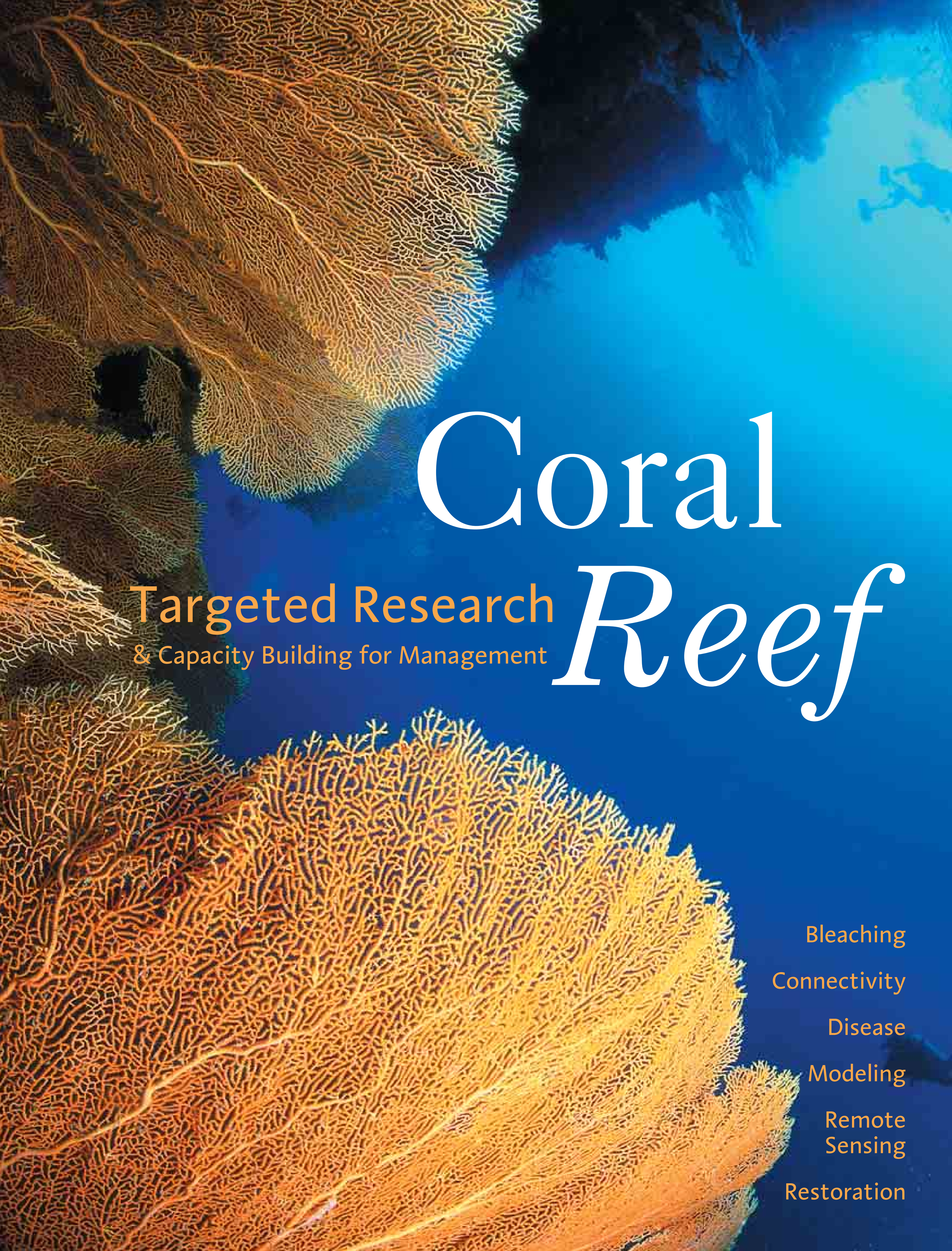


Coral *Reef*

Targeted Research
& Capacity Building for Management

Bleaching

Connectivity

Disease

Modeling

Remote Sensing

Restoration

Aerial photograph of hotel development in Cancun, Mexico adjacent to coral reefs.

Whether it's climate or higher population density, it's Global Change no matter how you look at it. The question is: can the ecological systems that support our well-being adapt to the pace at which such changes are taking place?

Our societies face unprecedented and mounting challenges in dealing with human population growth and expansion. Today, over one-half of the world population—more than 3.6 Billion people—live within 100 kilometers of the world's coastlines. Two out of three of the world's cities of over 2.5 million inhabitants are located in coastal regions. The pressures and transformations on these lands and seascapes are unprecedented in history—both with respect to the spatial coverage and the rate at which they are changing. Throughout much of the world, coasts are over-developed, over-crowded and over-exploited. As a global community, do we have to accept unsustainable transformation and loss of the resources that support our quality of life and welfare, or do we have the collective will and foresight to alter our course and sustain critical resources and services for ourselves, our children and theirs? The oceans occupy over 70% of the planet's surface, but our knowledge of their resources is only in its infancy.

Coral reefs occupy only 0.1% of the ocean's surface, yet they are the world's richest repository of marine biodiversity. They are the largest living structures on Earth—the only natural communities distinctly visible from space. Complex and productive, coral reefs have survived over the course of more than 400 million years of evolution, and possess richness, diversity of life and structure that are integral foundations for humanity. Within an equatorial band between the Tropics of Capricorn and Cancer, coral reefs are the life blood of nearshore, tropical waters and play a key role for the coastal populations that depend on food and resources for daily livelihoods.

Today, coral reefs around the world are in such serious decline that their defilement risks contributing to environmental and economic instability of many coastal nations. Many coral reefs have reached a state of decline that they can no longer be considered as coral reefs, while others are under increasing threat from local human disturbances and impacts from a changing global climate. Of the 109 countries with significant coral reef communities, over 93 are experiencing damage to them.

Although opinions abound as to the causes, the cumulative and interactive effects of stress on coral reefs and the implications for long-term sustainability of these ecosystems are simply unknown. While managers struggle to maintain a balance between use and conservation in deciding among complex tradeoffs, we do not know enough about the fundamental factors affecting coral reefs in many areas to make practical management decisions. And we are not adequately equipped with the understanding and the tools needed to manage and plan for changes brought about by the transformation of these ecosystems—especially over the past thirty years.

Today's environmental problems are increasingly complex and intractable—overwhelming for individual scientists and managers to resolve independently. There are indeed many actions that can and are being undertaken in working to reverse negative trends for coral reefs, and to raise awareness of their importance to coastal societies, but the tools in the tool-box remain woefully inadequate to manage in the face of acute impacts and multiple stresses.

What is needed is effective coordination and teamwork among the best minds in the world—to collaboratively uncover critical unknowns and then work with others to apply the information in practical and helpful ways.

This information brochure introduces a Global Coral Reef Targeted Research program, and the various entities that have come together to form this complex, yet critical undertaking. This program seeks supporters who share our global vision—to uncover outstanding, yet critical unknowns whose results will genuinely make a difference to society.

Our Partners:

The World Bank

Global Environment Facility

The University of Queensland, Australia

UNESCO - Intergovernmental Oceanographic Commission

United States National Oceanic and Atmospheric Administration

What is "Targeted Research"?

The Coral Reef Targeted Research and Capacity Building program has been established to address fundamental information gaps in our understanding of coral reef ecosystems, so that management options and policy interventions can be strengthened globally. For the first time in history, this project will join the collective effort of many of the World's leading coral reef scientists to coordinate research efforts and address key outstanding questions about the health of coral reefs. The program is being developed in phases over 15 years, and through focused and systematic research, is working to effectively support management and policy and to better integrate resulting information with other disciplines, such as economics and law. The program will also enhance the capacity of researchers, students and managers within developing countries, so that a global network can effectively share the most up-to-date research to benefit regional, national and local management actions and policy.

The Program is coordinated across geographic nodes that reflect the regional distribution of coral reefs and management initiatives underway to conserve them. The regional nodes will be the focal points for research carried out by international scientific working groups and integrated within an overall research framework consisting of three strategic elements:

- Addressing knowledge and technology gaps
- Promoting Learning and Capacity Building
- Linking scientific knowledge to management

A major focus of the Targeted Research Program is to build capacity in countries with coral reefs–to develop and sustain a robust research framework and to apply the findings in practical ways.

Coral Reef Targeted Research Capacity-Building Centers of Excellence

Addressing Knowledge and Technology gaps

Over the past ten years, an increasing awareness of the importance of coral reefs has been evident, especially in light of their rapid decline in many regions and their importance to developing countries. However, significant gaps remain in our understanding of many of the basic forcing functions and processes affecting coral reefs—to the extent that current management options remain severely limited. This targeted research framework is systematically identifying information gaps and prioritizing them in an order of strategic importance to management, so that the resulting information and tools developed can lead to credible outcomes.

From 1998-2001, scoping sessions were held with scientists and managers around the world to determine where the major gaps lay in the science and technology currently supporting coral reef management. Based on this effort six themes were identified and led to the formation of six working groups:

1. *Coral Bleaching and Local Ecological Factors*
2. *Connectivity and Large-Scale Ecological Processes*
3. *Coral Diseases*
4. *Coral Restoration and Remediation*
5. *Remote Sensing*
6. *Modeling and Decision Support*

The Working Groups

The Working Groups form the scientific basis for the program and are major areas in which additional knowledge is essential. The groups have developed priority investigations with the express intention to inform management. The Working Groups are represented internationally and include members from both developing and developed countries. Membership represents major researchers within specific areas of coral reef science.

Coral Bleaching and Local Ecological Responses

Ove Hoegh-Guldberg, Chair, University of Queensland, Australia

Members: **Yossi Loya**, Co-Chair, University of Tel Aviv, Israel; **Bill Fitt**, Cellular responses, USA; **John Bythel**, Local ecological responses, UK; **Rob van Woesik**, Local ecological responses, Japan/USA; **Roberto Iglesias-Prieto**, Molecular mechanism/markers, Mexico; **Ruth Gates**, Cellular responses, USA; **Barbara Brown**, Cellular responses, UK; **Michael Lesser**, Cellular responses, USA; **Ron Johnstone**, Local ecological responses, Australia; **Tim McClannahan**, Local ecological responses, Kenya; **Nyawira Muthiga**, Local ecological responses, Kenya; **David Obura**, Local ecological responses, Kenya; **Ole Vestergaard**, Coordination, IOC/UNESCO, France

The Bleaching Working Group (BWG) was founded by the UNESCO/Intergovernmental Oceanographic Commission (IOC) in April of 2001. The group's initial terms of reference included the development of indicators specifically for coral bleaching. Subsequently, it expanded its mandate to examine specific physiological mechanisms for coral bleaching as well as the local ecological factors that precipitate bleaching and its after-effects, and differences between direct human stresses with those related to climate change.

The Working Group has prioritized hypotheses at various levels of interaction related to stress tolerance and the basis for

Large scale bleaching affected the world's largest continuous coral reef in early 2002. More than 60% of the Great Barrier Reef bleached and up to 5% of corals were severely damaged.

Bleaching refers to the loss of symbiotic dinoflagellate algae, *Symbiodinium*, within the coral host leading to a bleached, white appearance. Bleaching is a stress response of the coral host and associated with elevated sea water temperature. Over extended time periods a bleached state can lead to death of the coral, and can occur over large areas of coral reef.

vulnerability and resilience of corals reefs to bleaching. Examples include the following:

- **Molecular-level Hypotheses:** i) The basis of heat stress tolerance in corals rests in the molecular mechanisms that reduce photoinhibition. ii) Failure of the primary steps of photosynthesis leads to a build-up of oxygen radicals, which then cause cellular damage. iii) Both coral host and zooxanthellae have a series of coral bleaching specific markers that may be useful as bio-markers.

- **Cellular and Physiological Hypotheses:** i) Coral bleaching and mortality is driven by the primary variable elevated temperature, but is influenced by light, flow and other factors. ii) Thermal stress will reduce growth rates, coral metabolism, and regenerative capacity. iii) Seasonal fluctuations in the density and quality of zooxanthellae are important to understand coral bleaching.

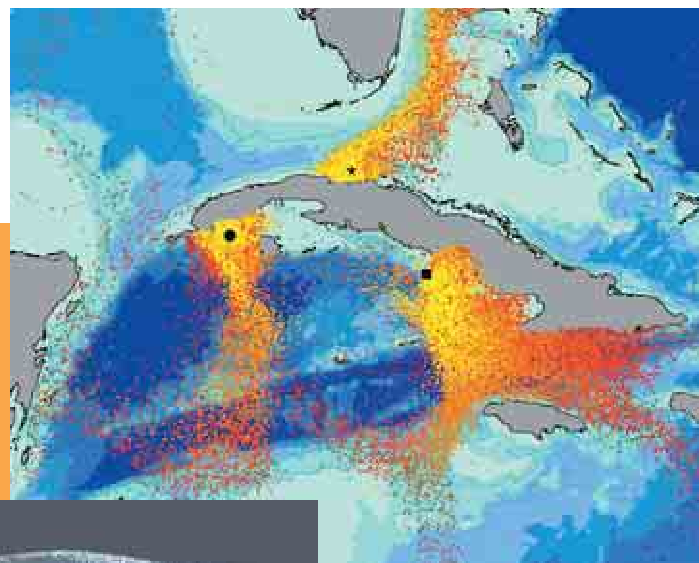
- **Within-Reef Ecological-level Hypotheses:** i) Climate change will reduce reef resilience by: increasing whole colony mortality on coral reefs, changing differential mortality patterns (species, size) reducing recruitment (loss during larval phase failure of settlement), having a greater effect on larval survival compared to the adult phase, causing a change in relative abundance of populations, size frequency distributions, and causing a functional shift. ii) Other stressors (natural and/or anthropogenic) will have a compounding effect on the tolerance of corals and zoox-anthellae to thermal stress.

Connectivity and Large-Scale Ecological Processes

Peter F. Sale, Chair, United Nations University and University of Windsor, Canada (fish ecology, recruitment)

Members: **Yvonne Sadovy**, Co-Chair, fisheries ecology, China; **Menchie Ablan**, fisheries genetics, Malaysia/Philippines; **Ernesto Arias**, fish and coral ecology, Mexico; **Mark Butler**, lobster biology, recruitment, USA; **Bob Cowen**, fisheries oceanography, larval biology, USA; **Geoff Jones**, fish ecology, recruitment, Australia; **Serge Planes**, fish genetics, France; **Barry Ruddick**, physical oceanography, Canada; **Bob Steneck**, coral reef ecology, coral recruitment, USA; **Alina Szmant**, coral biology, recruitment, USA; **Simon Thorrold**, fish otolith microchemistry, USA; **Bret Danilowicz**, fish recruitment, stock discrimination, Ireland/USA; **Ken Lindeman**, fish ecology, USA; **Enric Sala**, grouper biology, USA; **Mary Alice Coffroth**, coral genetics, USA

Coral reefs are patchily distributed in an ocean that provides the possibility of transport among them. Presently, the design of Marine Protected Areas (MPA) containing coral reefs and their implementation uses educated guesses to decide appropriate spatial scales and patterns of placement, and there is little information to determine whether these guesses are even approximately correct. As levels of direct exploitation of coral reef resources rise, and as other pressures on reefs and increased use of coastal environments intensify, it becomes increasingly important that the establishment of spatially explicit management is done at correct spatial scales – ones compatible with known patterns of "connectivity" of target populations.



This image represents a "virtual" model run to simulate the dispersal of lane snapper larvae from 3 spawning aggregations sites around Cuba. The pelagic duration of snapper larvae is about 30 days. The image is a snapshot and so does not represent changes over time. However, it implies the potential levels of connectivity between the Caribbean islands of Cuba, the northern Bahamas (Northeast), with Jamaica (Southeast), and to a much lesser degree with Mexico (Southwest).

Connectivity can be defined as the flux of items between locations. It exists for nutrients, sediments, and pollutants, but in the context of coral reef management, connectivity in the form of the effective transfer of individuals (usually pelagic larvae) between local populations is the most important, and also the most difficult to measure. While the transfers of non-living materials is likely to be determined primarily by local and regional hydrodynamics, we know that the transfer of organisms (demographic connectivity) is more complex since passive transport due to hydrodynamics is modified by the sensory and behavioral capabilities of marine larvae. Effective transfer also involves successful establishment as a part of a breeding population, so connectivity among populations is not simply measured by focusing on dispersal patterns, but must include successful recruitment to the receiving population.

At present we lack quantitative data on demographic connectivity, yet these data are essential if we are to improve our ability to design and implement networks of MPAs and other spatially explicit management systems. The use of MPAs presupposes connectivity. Either MPAs are established at a size believed large enough to encompass all phases of the life cycle of species being sustained, or they are established at a size, and in spatial arrangements with respect to unprotected sites, that will foster enhanced recruitment of species to these surrounding sites due to dispersal beyond MPA boundaries.

The Connectivity Working Group (CWG) is targeting these fundamental gaps in our knowledge. It is beginning its work in selected areas within the various regions of the program with the aim to develop specific tools and techniques necessary to address these critical questions. The Group's initial focus involves the following research:

- **Larval biology and behavior.** By studying several organisms simultaneously–ranging from spiny lobster with very lengthy larval phases, to corals with much shorted larval durations, to fishes with active larval swimming behavior—the CWG will provide critical knowledge of the potential of connectivity in furthering management and conservation.

- **Hydrodynamic and biophysical models to predict dispersal.** The spatial and temporal patterns in abundance of new recruits must be driven initially by patterns of dispersal from source locations in a region. Using biophysical models to track dispersal through larval life from selected source locations, it should be possible to generate maps of "settlement intensity" to compare with observed recruitment patterns. Congruence will suggest that models are sufficiently precise to describe patterns of connectivity among locations. Deviations will drive further work to improve hydrodynamic models, and to explore capabilities for active movement. The nature of the deviations will provide cues to factors that may be important in determining connectivity patterns for various species.

- **Genetics.** Flux experiments on corals and fish will use genetic data to reliably identify progeny from particular mass spawnings and dispersals. Coral studies will also use genetic patterns expressed in cohorts of differing age to determine if there have been measurable changes in patterns of connectivity in recent decades (during a time when Caribbean coral populations have suffered serious declines).

To what degree are coral reefs connected across space and time? Do they rely upon larval sources from elsewhere, or from local sources of seeding? Are larval sources dependent upon spawning aggregations, like this school of Baraccuda (below)?

- **Otolith chemistry** (inner ear bones within fishes). Work with fish will take advantage of the possibility that otoliths of larvae can be given a unique tag by administering a chemical to the females immediately prior to spawning. A second "marking" method will rely on collection of sufficient genetic information from the spawning aggregation that a "paternity analysis" can be used to screen collected recruits. The fish flux experiments will also tag the aggregating adults externally so that the "catchment area" of the aggregation can be established using tag returns to locate animals after they have dispersed.

- **Recruitment monitoring.** Studies of recruitment will be substantially extended by targeted research on early post-settlement survivorship and growth of selected species. The underlying hypothesis driving this work is that there are major bottlenecks to successful recruitment of corals that occur after completion of the larval phase. Understanding the causes of these bottlenecks, and therefore the conditions under which connectivity may or may not be achieved is clearly fundamental to a full description of coral reef connectivity.

Built into this targeted research, the CWG will be working with local managers and scientists in undertaking these experiments, so that genuine transfer of tools and techniques will take place, and so that a joint understanding of the findings will have direct application towards improved management.

Coral lesions and diseases have become prevalent within the Caribbean Sea, as shown in this species of massive coral (top) and Gorgonian sea fans (right). While the Caribbean has been previously reported as having the highest incidence of coral diseases, new findings supported by this Targeted Research program are showing that coral disease is also prevalent in other oceans, such as the Pacific and Western Indian Oceans.

Coral Disease

C. Drew Harvell, Chair, Cornell University, Ithaca, NY, USA

Members: **Garriet Smith**, Co-Chair, USA; **Bette Willis**, Co-Chair, Australia; **Farooq Azam**, USA; **Eric Jordan**, Mexico; **Eugene Rosenberg**, Israel; **Ernesto Weil**, Puerto Rico; **Laurie Raymundo**, Philippines/Guam

Over the last 20 years, unprecedented increases in disease on coral reefs have contributed significantly to coral reef degradation. Disease-related damage of coral reefs has been well documented in the Caribbean, but recent observations of coral disease in other regions of the world are just beginning, and disease occurrence in these other regions may be a potential harbinger for increasing outbreaks and impacts associated with increased climate warming. What has prompted this rapid emergence of coral disease? The Disease Working Group (DWG) is targeting investigations to address this question, to understand this emergent problem and to develop tools and responses that can be used for management. The Disease Working Group is basing its work program around the following major tasks and hypotheses:

- **Identify major coral diseases.**
  What diseases are global in their distribution?

- **Infectious disease significantly reduces coral reef biodiversity.**
  Can some diseases enhance biodiversity?

- **Coral disease (and pathogenic organisms) are higher during bleaching events and in more bleached locales.**
  Are bleached corals more sensitive to super-infection with other pathogens?

- **Coral Disease prevalence and severity are higher in high nitrogen eutrophic situations.**
  Does chronic stress (such as eutrophication) result in higher incidence of disease?

- **What is the host range of known coral pathogens?**

- **Remediation for coral disease.**
  Can antimicrobial agents limit infections?

Coral Restoration and Remediation

Alasdair Edwards, Chair, University of Newcastle upon Tyne, U.K.

Members: **Edgardo D. Gomez**, Co-Chair (Philippines), **Loke Ming Chou** (Singapore), **Andrew Heyward** (Australia), **Richard E. Dodge** (Caribbean), **Baruch Rinkevich** (Israel), **Aileen Morse** (USA), **Tadashi Kimura** (Japan), **Abdul Azeez Abdul Hakeem** (Maldives), **Helen Yap** (Philippines).

The world-wide degradation of coral reefs, particularly in the last two decades, has prompted greater attention to remediation and restoration. This has resulted in a wide range of initiatives broadly classified as improving the existing condition of impacted coral reefs (mainly through human influence). Early initiatives have focused more on artificial reefs where "reefs", or more accurately "fish-aggregating devices" are created on non-coral reef platforms, mainly to enhance fisheries production. While this approach is still being expanded more recent activities have been directed specifically at restoring degraded coral reefs.

The diversity and scale of remediation/restoration activities vary tremendously. They cover habitat modification, coral transplantation, species re-introduction, and recruitment potential enhancement. Some of these interventions involve large-scale sub-tidal structures designed to facilitate natural colonization of reef-related species, while others use simpler and less costly approaches that are more readily replicated. Reef remediation and restoration will continue to have an increasingly important role and efforts are likely to expand in the future. However, viable approaches and technologies are in relatively early stages of development, and in most cases are currently difficult to implement on large spatial scales.

Reef remediation/restoration should not replace reef protection as the first management option. However, large areas of degraded reefs make it unavoidable to ignore remediation and restoration action. The loss of biological and economic services from degraded reefs continually emphasize the need for maintaining the ecosystem, and where degraded, to restore it to a level where significance can once again be realized.

The Restoration and Remediation Working Group (RRWG) is examining the state of restoration and remediation techniques and is targeting investigations to test the efficacy of a range of potential applications. The research includes the following considerations:

- **the scientific protocols necessary to design and implement restoration strategies**
- **baseline data for developing effective criteria for restoration**
- **the efficacy, feasibility and cost effectiveness of restoration and remediation techniques**
- **prospects for enhancing natural recovery**
- **opportunities to combine reef remediation with small and micro-enterprise at the local level.**

The Restoration and Remediation Working Group will coordinate its investigations with other Targeted Research Working Groups to consider implementing joint research into remediation or restoration options, especially with the Bleaching, Disease and Connectivity Working Groups.

Stands of the elkhorn coral, *Acropora palmata*, at Carysfort Reef in the Florida Keys between 1975 and 1985.

Remote Sensing

Peter J. Mumby, Chair, University of Exeter, U.K

Members: **Laura David**, Co-chair (Philippines), **Ian Gillett** (Caribbean, Belize), **Jack Hardy** (Caribbean, Indo-Pacific, USA); **Eric Hochberg** (Caribbean, Indo-Pacific, USA), **Ellsworth LeDrew** (Caribbean, Indo-Pacific, Canada), **William Skirving** (Indo-Pacific, Australia); **Al Strong** (Caribbean, Indo-Pacific, USA); **Mary Vasquez** (Caribbean, Belize) **Stuart Phinn** (Indo-Pacific, Australia), **Pat Colin** (Indo-Pacific, Palau), **Dave Idip** (Indo-Pacific, Palau).

The Remote Sensing Working Group (RSWG) will be developing and testing a wide range of remote sensing tools, including satellite, airborne, acoustic and in-field methods. Prior to this Targeted Research effort, the remote sensing of coral reefs has been conducted on an ad-hoc basis with little consistency or general insight into its limitations. For example, we know that some aspects of coral reef health can be resolved on shallow reefs in French Polynesia but we cannot predict whether this would be a realistic expectation in say Jamaica, where reefs have a different flora and fauna, are located in deeper water, and where light penetration is slightly reduced because of higher suspended sediment concentrations in the water column. Without a generic understanding of the limitations of coral reef remote sensing, the technology may continue to be oversold or deployed for unrealistic management objectives, resulting in an inappropriate use of financial resources.

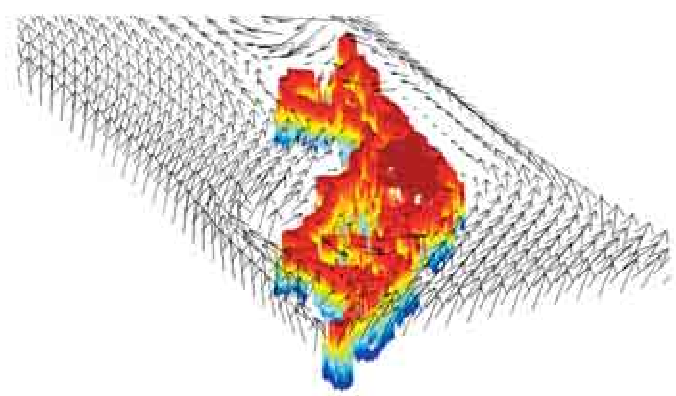
The RSWG will quantify the limitations of coral reef remote sensing by combining modeling and field experiments. Models predict the ability of a given remote sensing instrument to detect the subtleties of bottom reflectance that distinguish reef habitats or the cover of corals and macroalgae within habitats. While the passage of light through the water column is relatively well understood, the interaction of light between reef organisms, many of which have complex structures, presents a research challenge. We address this problem using methods which were originally developed in the computer graphic industry. Coral structures are divided into thousands of individual patches, each of which behaves as a specialized reflecting surface. On reaching the reef, sunlight is reflected and scattered in predictable directions, from which we can calculate the net light recorded by the sensor once it has passed back through the water and atmosphere. Computer models will be refined and tested in the laboratory and then tested under field conditions in a unique, large-scale remote sensing experiment.

The RSWG will also provide tools to identify various coral reef habitat types and possibly predict the cover of corals and algae on a reef. These tools require high resolution imagery and direct field survey at the time of image acquisition and therefore have limited application to archived or lower-resolution imagery. A wealth of satellite and photographic data are often available for reefs, sometimes archived as far back as World War II. We will conduct a number of activities to improve the way in which changes in reef condition can be predicted indirectly using remote sensing. These methods will highlight which areas of the coast have undergone the greatest change and help managers quantify the rate of change in coral reef habitats.

Satellite (IKONOS) image of Heron Island, Australia, captured in April, 2004, immediately following a period of coral reef bleaching. Heron Island is the small land mass (brown) to the left of the image, whereas most of the living reef structure can be seen as light brown. Note the living patch reefs (seen as small dots) in the center of the image. The bright white dots surrounding the edges of the reef are waves. The RSWG is using this and other images of coral reefs to determine the degree to which change detection may be possible over large areas.

Recent remote sensing research has improved the detail of reef habitat maps but the interpretation and uses of these products for management and measuring and evaluating biodiversity has received relatively little attention. Specifically, what do habitat maps mean in terms of biodiversity and reef function and how should they be used for conservation planning and to sustain resources? For example, many reserve selection algorithms require an extensive database of species' distributions which are costly and logistically difficult to establish. Remote sensing could largely replace intensive site-specific biodiversity surveys if the value of habitats as a surrogate for species (or functional) diversity can be effectively established in a variety of environments. The Targeted Research framework provides an unrivalled opportunity for taxonomic capacity within its Centers of Excellence and to quantify the ecological basis of habitat maps.

In addition to improving the capability of remote sensing to help assess coral reefs, this working group will also provide technical assistance to the other working groups that might benefit from the use of remote sensing products to complete their investigations. Finally, the RSWG will organize a wide variety of oceanographic and atmospheric remote sensing products into an International Oceanographic Atlas and will make them available for coral reef and coastal management within a single website.



The estimated bathymetry (or bottom topography) to 30m around the major island group of Palau. The darkest red represents land and the top of the barrier reef, while blue indicates 30m deep water. The bathymetry was produced using satellite data combined with measurements in the field. Surface currents typical for the December-March period are illustrated by the vectors.

Modeling and Decision Support

Roger Bradbury, Chair, Australia National University, Australia

Members: **Roger Bradbury**, Chair, Australian National University, Australia; **Pascal Perez**, Co-chair, Australian National University, Australia; **Porfiro Aliño**, Philippines; **Ernesto Arias**, Mexico; **Peter Campbell**, USA; **Bohdan Durnota**, Australia; **Craig Johnson**, Tasmania; **Richard Pollnac**, USA; **Robert Seymour**, UK.

The purpose of the Modeling and Decision Support Working Group is to create an integrated scientific understanding of the way in which people interact with coral reefs. The MDS will work to help decision makers and reef users better understand and use reefs in a sustainable way, by helping to understand the dynamics of whole system—that is, both the biophysical and socio-economic parts. The task is multidisciplinary, multi-scaled and highly spatial. It deals with the complex phenomenology of coral reef ecosystems together with the equally complex phenomenology of the associated human socio-economic systems.

The research problem falls squarely within the new discipline of complex systems science. This discipline started to become coherent in the 1980s and is now an area of active research on problems like coral reef decline, and on analytical and modeling techniques. There are now stand-alone institutes (like the Santa Fe Institute), major government research initiatives (such as at Argonne National Laboratory, CSIRO Centre for Complex Systems Science or France's CIRAD), and university centres (such as CoMPLEX at University College London) and consortia (such as New England Complex Systems Institute or the EU's Exystence). This effort, while not all directed at sustainability issues, has produced a body of research work and a community of practice that has made great progress in taming large unruly problems like coral reef ecosystems present.

The hard-won experience of these research groups tells us that "the coral reef problem" is tractable with current knowledge and techniques, but that we should not expect a traditional scientific solution —some sort of grand unified analysis and prediction. Complex systems are not, in principle, predictable. Instead we should expect progress to come in the form of clusters of models that help us understand the present dynamics and explore possible futures. In the best outcomes, this exploration can become an integral part of the policy development process in an ongoing iteration between scientists and decision makers.

The MDS group will build its program taking advantage of complex systems science, and because this is a new discipline, the MDS group intends to ensure that its clients and stakeholders develop an understanding of the strengths and limitations of the complex systems approach. Experience in other large complex projects has shown the best way to do this is through a process of top-down and stepwise-refinement model building to create clusters of models. We have also learned that strong visualisation metaphors of the system are highly effective in engaging widely different stakeholders.

Top-down modeling starts with the whole problem and gradually breaks it down in to its components. In contrast, bottom-up modeling starts with the fundamental components of the system and joins them together to model the whole system. Top-down modeling allows the model builders to interact with the users and build models that are relevant and meaningful to them in a transparent way.

Stepwise-refinement means that the model building proceeds through iterative steps each of which progressively refines the understanding of the problem and elaborates the complexity of the model. The depth to which the modeling eventually develops is not set by any hard and fast rule, but rather by the sufficiency of understanding created for both modelers and users. In this way, the users and stakeholders have an important and continuing say in how the modeling develops. Thus, the integration of socio-economic and biophysical components, the stakeholder involvement and training, and the building of capacity are being integrated into this process from the beginning.

Clusters of models have been shown to be particularly effective when a range of disciplines is involved, or when the types of questions posed are themselves evolving. And even in some traditional "unified" models, such as oceanography or meteorology, where the range of disciplines is restricted and the questions clear, clustering is beginning to become a strategy of choice.

Visualisation is another vital component of a research strategy for complex systems, like coral reefs. Much of our subject matter has a strong spatial component, and so presenting model results as maps is an obvious and important way to engage users. Maps have been found to be particularly powerful ways of reaching across disciplinary divides, and for reaching out to non-technical users. And it is the visualisation of information rather than the spatial analysis that allows disciplines to be transcended, and scientists to meaningfully engage with other users of information.

In the Field

Four regional nodes have been selected that reflect the distribution of coral reefs throughout the world. The nodes represent the three major coral reef regions of the world – the western Pacific (which is the center of coral reef biodiversity), the Indian Ocean (which has suffered extensively from recent episodes of coral bleaching associated with climate change), and the western Atlantic (whose reefs are substantially different from Pacific and Indian Ocean reefs). Each of the working groups will conduct core elements of their investigations in at least two of the four regional nodes during the first five years of the Program.

Within each node a research institution with the capacity to serve as a regional Center of Excellence has been identified as follows:

Western Caribbean: Unidad Académica Puerto Morelos, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México

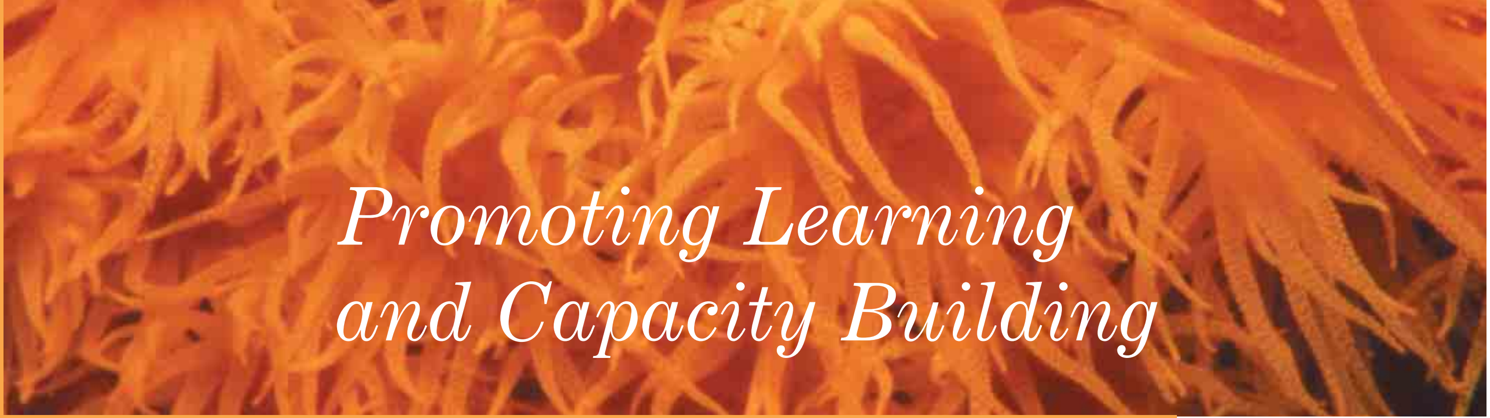
Eastern Africa: University of Dar Es Salaam, Marine Science Institute, Zanzibar, Tanzania

Southeast Asia: Marine Science Institute, University of the Philippines, Bolinao Marine Laboratory

Central south Pacific/Australasia: Heron Island Research Station, The University of Queensland, Australia

The locations and institutions have been selected on the basis of significant ongoing investments in coral reef management and where considerable baseline data already exist, along with a critical mass of coral reef scientists and infrastructure—essential to carrying out coordinated research. The Centers serve as a convening location for each of the Working Groups, so that research can be discussed and implemented with regional and local scientists in a collaborative spirit. Research plans, standard methods and development of capacity are being coordinated to maximize the level of effort between as many of the sites and working groups as possible. Over the 15 year planned phase of the project, the number of study sites will increase to strengthen research results.

Experimental mesocosms, like these tanks containing small coral replicate samples, help control physical variables to better understand the underlying physiological mechanisms of various coral reef stressors, such as elevated temperature, light radiation, nutrients, pollutants and other factors. This research was initiated during a 2002 coral bleaching workshop of the Targeted Research Program, and is being established at each of the Centers of Excellence.



Promoting Learning and Capacity Building

Building scientific and management capacity in countries where coral reefs occur is a major thrust of the Targeted Research program. Support for capacity building will center on the regional nodes and development of the Centers of Excellence to serve as the focal points for scientific learning exchanges. The project will support a series of workshops at these centers each year which will bring researchers from the various working groups together to orient field research, brief one another on findings and, based on these results, modify and design the subsequent phases of targeted research. Through the Centers of Excellence in each of the four regions, working group members will engage with other researchers from within the region, as well as other working groups, and will jointly conduct investigations, share knowledge and engage in training opportunities with doctoral and post-doctoral fellows from participating developing countries. Based on experiences during the project development phase, apprenticeship-type models proved to be highly successful by combining world-class, seasoned researchers with younger post-doctoral fellows and graduate students in a supportive working environment. This brings international expertise in the development and use of various techniques and investigative strategies that will provide opportunities for regional and local researchers. The involvement of post-graduates is supported through stipends and research scholarships.

A major benefit of the Targeted Research program is the interactions between coral reef researchers in both developed and developing countries. Members of the RSWG and RRWG discuss remote sensing images during a meeting in the Philippines.

The Centers of Excellence will also serve as focal points for the network of scientists to engage with managers, NGOs, local stakeholders and other interested groups. These groups will participate in targeted learning exchanges about a management and policy implications of the research and how such coordinated information can be integrated into practice. The meetings also present opportunities for the scientific community to learn and benefit from the knowledge of local stakeholders, especially those who may possess traditional and local knowledge of coastal and marine resources.

Linking Scientific Knowledge to Management

The targeted research framework has been designed to support managers, policy makers, and other stakeholders, and the results generated will be formulated for application into management and policy contexts. Over the course of program's implementation the information and tools produced will be disseminated as knowledge products to enhance management approaches and interventions and to inform policies that affect coral reefs at local, national and regional levels.

The Synthesis Panel

A guiding Synthesis Panel has been formed to give direction to the Targeted Research program and ensures that the whole is greater than the sum of its parts. The Panel, comprised of the chairs from each of the working groups and representatives from each of the Centers of Excellence plus additional professionals and scientists, steers the targeted research framework, modifies study designs and the focus of investigations, reviews results, and helps synthesize and interpret the data in formulating conclusions and applications.

The Synthesis Panel will serve as a key interface in bringing findings of coordinated scientific research into discussion with other disciplines, such as Economics and Law, and also assists the Working Groups in reporting summary findings to the scientific and management communities, and to make policy recommendations where appropriate.

Periodic symposia will be convened to engage public policy makers in discussions of research outcomes and to build support for policy reform where appropriate. By helping to inform management and policy with the knowledge required for sound decision making, the Targeted Research Program seeks to overcome an important obstacle to effective management. Informed policies, coupled with investments to improve the socio-economic welfare of coral reef-dependent countries can only improve the prospects for the conservation of the world's coral reefs.

The enclosed leaflets describe the Working Groups, Centers of Excellence and the Targeted Research Program in greater detail.

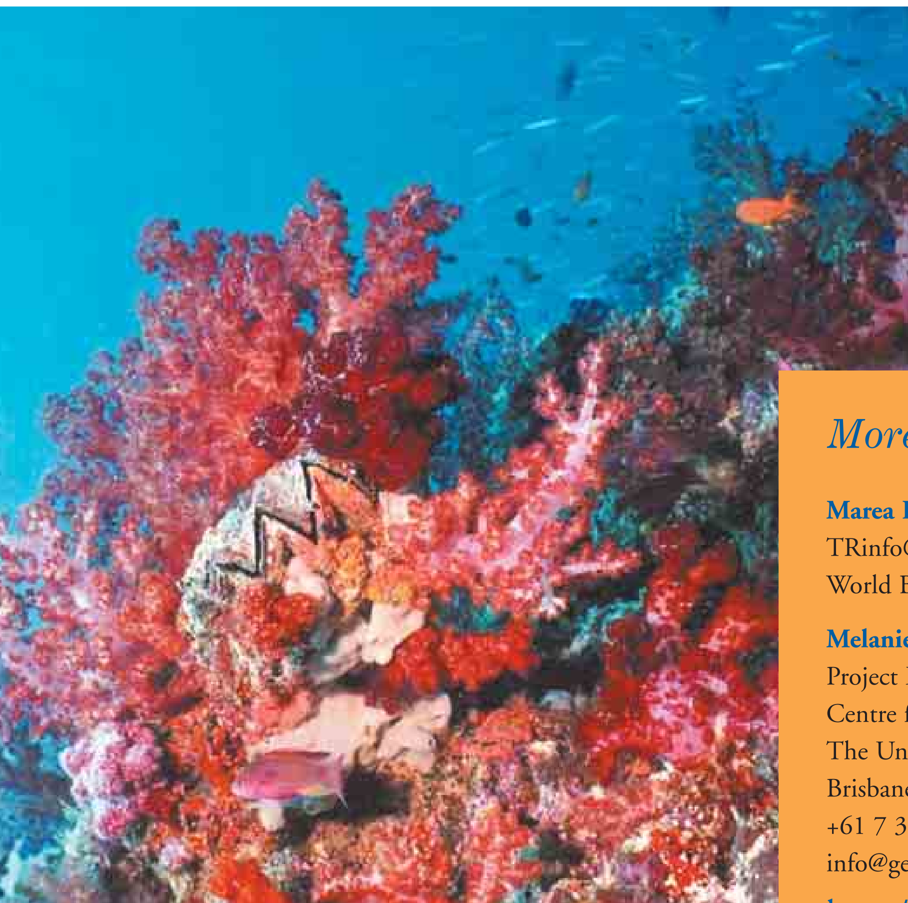
The Synthesis Panel:

Nancy Knowlton,
Chair, Scripps Institute of Oceanography, La Jolla, CA USA

Robert T. Watson
Senior Science Advisor, The World Bank

John Dixon
Lead Natural Resources Economist, The World Bank (Retired)

Other members of the Synthesis Panel include management and capacity building professionals, representatives from each of the Centers of Excellence and the Chairs of the six Thematic Working Groups, plus a senior representative from The University of Queensland and UNESCO-IOC.



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Coral *Reef*

Targeted Research
& Capacity Building for Management

Centers of Excellence

Puerto Morelos Marine Laboratory, Instituto de Ciencias del Mar y Limnología, Universidad Nacional Autónoma de México (UNAM)

Heron Island Research Station, The University of Queensland Center for Marine Studies, Australia

Bolinao Marine Laboratory, University of the Philippines, Marine Science Institute

Institute of Marine Science, Zanzibar - University of Dar Es Salaam, Tanzania