WORLD

Global Coral Reef Targeted Research and Capacity Building Project

GEF Project Brief

Other

ENV

Date: October 6, 2003
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Project ID: P078034
Focal Area: I - International waters

Team Leader: Marea Eleni Hatziolos
Sector(s): General agriculture, fishing and forestry sector (100%)
Theme(s): Other environment and natural resources management (P)

Project Financing Data

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For Loans/Credits/Others:
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GLOBAL ENVIRONMENT FACILITY	0.00	11.00	11.00
FOREIGN UNIVERSITIES	0.00	17.09	17.09
Total:	0.00	28.09	28.09

Borrower/Recipient: MEXICO, TANZANIA, PHILIPPINES
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Estimated Disbursements (Bank FY/US$m):

FY									
Annual									
Cumulative									

Project implementation period: May 2004 - March 2009
Expected effectiveness date: **Expected closing date:**

A. Project Development Objective

1. Project development objective: (see Annex 1)

The Global Environment Objective is to align, for the first time, the expertise and resources of the coral reef community around key research questions related to the resilience and vulnerability of coral reef ecosystems, to integrate the results, and to disseminate them in formats readily accessible to managers and decision-makers. A related objective is to build much-needed capacity for science-based management of coral reefs in developing countries, where the majority of reefs are found. **The Project Development Objective** is to fill critical gaps in our global understanding of what determines coral reef ecosystem vulnerability and resilience to a range of key stressors—from localized human stress to climate change--to inform policies and management interventions on behalf of coral reefs and the communities that depend on them. These objectives will be achieved through targeted investigations involving networks of scientists, in consultation with managers, and the dissemination of knowledge within and across regions.

2. Key performance indicators: (see Annex 1)

Because the Project will support targeted research, which is necessarily a long-term process, project impacts cannot be fully measured within a five year time frame. Expected outcomes focus on process, knowledge products and capacity, as benchmarks for improved management and stress reduction policies leading to the sustainability of coral reef ecosystems, the long-term goals of the Project. In this light, key indicators of project success are described as follows:

1. Formerly fragmented research efforts are coordinated and targeted for the first time around key sustainability themes. A coalition of scientists and research institutions from developed and developing countries is built to support this effort.
2. Major partners from different sectors are aligned with this initiative, building momentum toward a critical mass of resources and a sustained effort.
3. Research results are peer reviewed, synthesized and broadly disseminated to a wide array of stakeholders.
4. Coral reef managers are empowered with knowledge and tools to make better decisions.
5. Institutional and human capacity for science-based management of coral reef ecosystems is built in countries where coral reefs are found
6. Policies in these countries to protect coral reefs or mitigate impacts from key stressors are strengthened as a result of new information
7. Research findings are mainstreamed into World Bank country dialogue and assistance strategies for countries with coral reefs.
8. Coral reef management projects under early implementation or in preparation—many with GEF support—incorporate findings into project design.
9. The GEF uses results to guide future resource allocations to address cross cutting issues in Climate Change, International Waters and Biodiversity and to guide clients in the design of large-scale targeted research.

B. Strategic Context

1. Sector-related Country Assistance Strategy (CAS) goal supported by the project: (see Annex 1)

Document number: n/a **Date of latest CAS discussion:** n/a

The global nature of this Project directly supports the Bank's corporate goals for environmental sustainability outlined in the **Environment Strategy (2001)**. The Strategy's goals of (i) improving quality of life, (ii) improving quality of the environment and (iii) protecting the global commons are all enshrined in

the Targeted Research Project's global objective of enhancing the sustainability of coral reef ecosystems through science-based management, for the benefit of the world's coral reefs and the communities that depend on them. 80% of coral reefs occur in developing countries, with Small Island Developing States (SIDS) almost completely dependent on their coral reefs for security and livelihoods. Tourism is the largest earner of foreign exchange for most SIDs, and for tropical countries with extensive coastal zones (e.g., Mexico, Belize, Honduras, Tanzania, Indonesia, Philippines), marine tourism is the fastest growing sector of the tourism market. In addition to supporting a growing international and local tourism market, coral reefs provide nutrition and livelihoods for millions of people through fishing and tourism related services. They are essential to environmental security for coastal communities, where one half to two thirds of populations are concentrated, providing shoreline protection against erosion and the damaging effects of storms and sea-level rise associated with climate change. Although they occupy only 0.1% of the ocean's surface, coral reefs are the world's richest repositories of marine biodiversity, and are the largest living structures on earth. Like their terrestrial counterparts, the rainforests, coral reefs support an array of environmental goods and services, whose ecological, cultural and economic value exceed our current capacity to quantify.

Yet, despite their global significance, coral reefs are in decline worldwide. Science magazine devotes an entire issue (August 15, 2003) to the spectre of coral reef decline. In a lead review article, entitled *Climate Change, Human Impacts and the Resilience of Coral Reefs*, the authors identify a range of human stressors on reefs whose intensity and frequency have resulted in a global threat to coral reefs. The cumulative impact of this threat is exacerbated by historically high rates of climate change and climate variability, which together place enormous stress on the ability of reefs to adapt. The Global Status of Coral Reefs 2002 Report, lists two thirds of the world's reefs as under severe threat from the cumulative impacts of economic development and associated impacts of climate change. Calls for protection and more sustainable use of coral reef ecosystems have been a familiar theme in global fora, from the International Coral Reef Initiative (launched in 1995, in which the Bank played a key role), to the Convention on Biological Diversity (1995), the International Tropical Marine Ecosystems Management Symposia (ITMEMS I and II, 1998 and 2003, respectively), and most recently, the World Summit on Sustainable Development (2002). The WSSD Plan of Implementation identifies coral reefs as unique and vulnerable ecosystems that play a crucial role in the economies of SIDs and other developing states, and urged partners to: (i) implement the Framework for Action of the International Coral Reef Initiative (ICRI); (ii) implement the Jakarta Mandate on Marine Biodiversity of the Convention on Biological Diversity; and (iii) strengthen capacity globally to manage these ecosystems through science-based management and information sharing.

While many conservation and management initiatives have been launched in response to these calls (the Bank, in partnership with the GEF and others currently has over $270 Million in active or pipeline projects), the effectiveness of these interventions is undermined by a paucity of information about what determines ecosystem sustainability and resilience to major disturbance events in an environment of increasing and variable stress. This information can only come from robust empirical observation and research on stress/response interactions, analysis of ecosystem drivers and threshold points and the tools to mitigate these effectively. Such systematic research must be targeted to management needs and of sufficient temporal and geographic scale to discriminate long-term trends from background noise and local ecosystem response from larger scale, potentially global effects.

The 1997/98 massive coral bleaching episode tied to an El Niño event, in which an estimated 30% of the world's coral reefs were affected, was a wake-up call to coral reef scientists and managers alike. Managers of reefs in the Western Indian Ocean, off Central America and in parts of the Pacific were faced with unprecedented bleaching and mortality as a result of sustained increases in sea surface temperatures (SST)

only one-two degrees centigrade above the mean. While bleaching events due to stress from elevated SST, sedimentation and changes in salinity (e.g., from storm runoff) were recorded in the literature, long-term time series data on how individual reefs responded over time to these events, differential mortality and difference in rates of recovery within and between reef systems were lacking in all but a few cases, making it difficult to discern patterns of vulnerability from past events or to predict the breadth and pace of recovery. Understanding the relevance of variations in time and space is an important factor affecting coral reefs for which little is currently known. The increasing frequency of El Niño and other disturbance events makes answers to such questions imperative:

- whether early warning systems are feasible (e.g., through direct measurement of stress in coral communities, or models of elevated SST and coral bleaching),
- whether bleaching and associated mortality can be mitigated and how, and
- whether natural recovery of damaged reefs may be enhanced through restoration at cost-effective scales.

Similar questions have been raised in the context of disease in corals and other reef species, which have been recorded with alarming frequency in the Caribbean and now threaten parts of the Pacific, including the Great Barrier Reef. Preliminary studies suggest a correlation between the plethora of new diseases discovered and their rate and mode of transmission (epizootiology) and climate change. Some hypotheses even suggest a relationship between coral bleaching and disease, with the former precipitating the latter.

Without understanding of ecosystem processes and how they interact with the range of stressors facing coral reefs today, management interventions, short of complete removal of the sources of stress, will continue to be largely guesswork. The precautionary principle is currently our best tool to counteract threats from economic development and climate change whose impacts we do not fully understand. This is, however, a blunt instrument which is both economically and socially costly, and hence rarely applied.

An alternative approach is to support management with targeted research. This involves asking the right questions, e. g., to identify major bottlenecks or drivers to sustain coral reef ecosystem goods and services, or to improve the cost-effectiveness of applications of existing tools, like Marine Protected Areas and coastal and ocean zoning, remote sensing and modeling. Targeted research may also lead to development and application of new tools, such as biotechnology, in the design of bio-indicators of reef stress or resistance to bleaching, and in the identification of pathogens and their pathways of transmission. At the macro scale, this might involve the development of new tools like genetic markers to reveal connectivity between reef systems or techniques to enhance natural recovery and restore reefs damaged from blast fishing or cyanide. This new knowledge, disseminated and linked to decision-making, has the capacity to dramatically increase the effectiveness of current and future management interventions. It also lends credibility and accountability to decision-making and has the potential to generate the political will needed to make tough trade-offs between conservation and intensive use.

The Coral Reef Targeted Research Project is being designed as part of a long term program that will be implemented in phases. The first five-year phase will initiate research in areas with significant coral reefs and Bank/GEF investments. These include sites in Mesoamerica, East Africa, Southeast Asia, and the Southwestern Pacific. Research nodes will be established at institutions that have the capacity to develop into Centers of Excellence in the region, and that may serve as resources and information clearing houses to satellite sites (involved in collaborative research or management), within and between regions. (see section C.2.)

The Regional Environment Strategies for LAC, AFR and EAP mirror the Corporate Strategy's

commitment to protect the global commons and the integrity of the environment as a basis for sustainable economic growth. Yet despite the reliance on coral reefs of all the countries in which the targeted research will be carried out initially (e.g., in Mexico, Belize, Tanzania, Philippines, and PNG), for such things as tourism, livelihoods, nutrition and security, only one of the CASes refers specifically to reefs as strategic development resources. This points to the continued emphasis on terrestrial resources and the need for better valuation of reef ecosystem goods and services. This project will indirectly help to make the links between coral reef sustainability and more secure livelihoods for coastal communities. It will directly contribute to safeguarding global commons of outstanding ecological, cultural, and biodiversity value. At the same time, it will build capacity within reef countries to frame and investigate key questions related to the sustainability of resources on which they depend. And finally, the Project will disseminate this knowledge globally and promote its uptake by key decision-makers influencing policies that affect coral reefs.

1a. Global Operational strategy/Program objective addressed by the project:

Coral reef ecosystems are open and trans-boundary in nature by virtue of the of flow of nutrients, pollutants, larvae, and adults of migratory species across ecosystem boundaries, and often national frontiers. Pollutants entering the system are primarily land based, emphasizing connections between drainage basins and shallow, coastal receiving waters, where most coral reefs are found. Coral reefs are a major feature of Large tropical Marine Ecosystems. They are extraordinarily diverse and generate an array of environmental goods and services which are dependent on reef integrity and the maintenance of ecosystem processes. Effective governance of transboundary aquatic resources is a hallmark of the IW Focal Area. The Targeted Research Project responds to the strategic priority for the International Waters Focal Area identified in the GEF FY03-FY06 Business Plan to: "Expand global coverage to other water bodies of cross-cutting foundational capacity building and innovative demonstration projects."

Through a series of highly integrated investigations in four coral reef regions of the world, the TR Project will target research to answer key questions related to coral reef vulnerability. It will explore the role of ecosystem processes as the basis for resilience and sustainability in response to major forms of stress. By bridging knowledge gaps related to impacts of climate change and localized human stress on the sustainability of trans-boundary aquatic ecosystems, the project fits within the Integrated Land and Water Operational Program, OP 9. However, by virtue of its cross-cutting investigations, which will shed light on the relationship between the effects of climate change on coral reef ecosystem integrity, including biodiversity and connectivity between reefs, as well as between watersheds and aquatic ecosystems, the project will have benefits in several different focal areas and operational programs, e.g., f GEF OPs 2, 8,10 and 12. It may also form the basis for a future joint program of work envisioned between Climate Change, IW and Biodiversity within the Bank.

As noted above, the Project will support capacity building across GEF Focal Areas, by creating a robust scientific framework within developing countries to investigate the basis for ecosystem vulnerability and resilience to climate change and localized human pressures. Impacts on ecosystem structure and Biodiversity will also be examined as part of these investigations. The model for establishing global networks of researchers to jointly investigate topics of high priority for coral reef ecosystem management, and to link the results to policy and decision-making, is eminently transferable to other focal areas and themes. This cross-cutting outcome for capacity building is also identified in the GEF FY03-06 Business Plan as a priority for the third replenishment phase:

..."Cross-cutting capacity building projects will support capacity building activities outside the scope of any one focal area but common to achieving the goals of all focal areas. Such activities, particularly

focusing on LDCs and SIDS, will include: (i) foundational capacity building, to establish the basic capacity of a country to meet its global environmental and sustainable development goals."

The joint investigations and targeted learning that result from collaborative, applied research, involving networks of developed and developing country scientists, will build the foundation for knowledge-based management and policies. The research findings and cutting edge tools developed will be disseminated periodically through a series of management and policy briefs aimed to improve our global capacity to manage coral reef ecosystems.

2. Main sector issues and Government strategy:

The main threats to coral ecosystem sustainability stem from localized impacts of human pressure and accelerated climate change. These threats are aggravated by governance issues related to inadequate information on the cumulative and interactive nature of these impacts on reefs and reef-dependent human communities, the short-term planning horizons of decision-makers, and the political tradeoffs associated with economic gains from intensive use (leading to irreversible change in some cases) vs. longer-term conservation benefits. Human impacts include (i) over-fishing and destructive fishing techniques, which alter trophic levels and destroy the ecological integrity of reef communities; (ii) land-based sources of pollution (e.g., sedimentation from deforestation and other poor land-use practices, eutrophication and Persistent Organic Pollutants (POPs); (iii) habitat loss from land reclamation and construction. Impacts associated with climate change include (i) increased sea surface temperature, sea-level rise and storm frequency and severity, and (ii) changes in ocean chemistry, all of which undermine reef growth and the physical integrity of coral reef ecosystems. Together, these impacts have resulted in the direct physical destruction of reefs and their decline through a variety of mechanisms, including coral bleaching, diseases, overgrowth of corals by seaweeds and outbreaks of predators. While public sector policies have tended to be shortsighted, often accelerating reef degradation and loss, management interventions have relied on surprisingly little empirical information, have been largely reactive to disturbance events, and fragmented. Up until now, research concerning coral reefs has been dominated by independent, and often opportunistic, lines of investigation. This has led to a fragmentation of research efforts and a difficulty in distilling information that can be compiled globally and directly applied to conservation and management. Furthermore, the process-response models historically used to address environmental degradation have been primarily reactionary in their approach and scope rather than pro-active. What is lacking are strategic research frameworks that establish critical baselines in representative locations, determine root causes and forcing functions under different stress regimes, and yield results, through scenario building and other decision support tools, that help managers anticipate problems as part of a risk management approach. Ideally, such research should also provide managers with a suite of cost-effective ***preventative*** measures, as well as an analysis of feasible restoration options. Such results would have tremendous application in helping guide current conservation and management activities now under implementation with support from the GEF and its partners, as well as helping to direct future management efforts.

3. Sector issues to be addressed by the project and strategic choices:

Addressing these challenges will require a new research paradigm. Based on agreed priorities identified in extensive consultations with coral reef scientists and managers during the Block A phase, this project seeks to coordinate and target research for the first time in this community's history. It will establish a global network of eminent coral reef scientists working together across disciplines and regions so that (i) key knowledge gaps can be systematically addressed to reduce uncertainty in the context of management , (ii) targeted research is multidisciplinary, drawing on a blend of biophysical and social sciences, (iii) the research is integrated across space and time to allow for a synoptic view of coral reef ecosystem dynamics in response to stress at local, regional and global scales and (iv) research findings are effectively communicated to decision-makers. (vi) These findings will be followed up at the policy level, by the Bank in country dialogue with clients with coral reefs, as to appropriate policy actions and investments.

Strategic choices involve the design of a global project for targeted research vs. a series of regional or national-level projects to support science based management of reefs. Other strategic choices involve the institutional arrangements and flow of funds for a global project which will be implemented across four sub-regions. Another key strategic choice has been to focus capacity building on creating the investigative framework and robust methodology to prioritize and test hypotheses in the field that will *inform* management, rather than to focus on management *per se*. Other initiatives, like the International Coral Reef Action Network (ICRAN) and NGO supported community-based management efforts are designed to focus on the latter. This strategic choice has clear implications for the fundamental nature and design of the Targeted Research Project.

C. Project Description Summary

1. Project components (see Annex 2 for a detailed description and Annex 3 for a detailed cost breakdown):

Below are summarized the overall components of the TR project, the structure of the participating elements, the key reforms to be sought, the benefits and target population, and the institutional and implementation arrangements.

Project compnents are organized around the following three needs:

a. 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 significance to developing countries. However, what remains fundamentally unknown about these ecosystems is alarming, especially when management interventions are becoming increasingly important. Significant gaps in understanding some of the basic forcing functions affecting coral reefs remain. This targeted research framework will systematically define those information gaps, and prioritize them in an order of strategic importance to management, so that the resulting information and tools developed can lead to credible outcomes. Figure 1 shows the intent of a thematic integration coordination between the working groups at a given site. Based upon fiscal limitation, not all working groups can begin targeted investigations in all 4 regions initially. However, the intent is to have all working groups engaged in all locations within the project's first phase. Figure 2 shows the locations and stages in the project at which the working groups will engage within each region. Standard operating procedures are being developed to ensure that working groups assist one another by conducting sampling and experimentation, where relevant, on each other's behalf. Furthermore, policies developed at regional and national levels can also be strengthened to help bring about better legislation to sustain the products and services provided to SIDS and coastal communities by coral reefs.

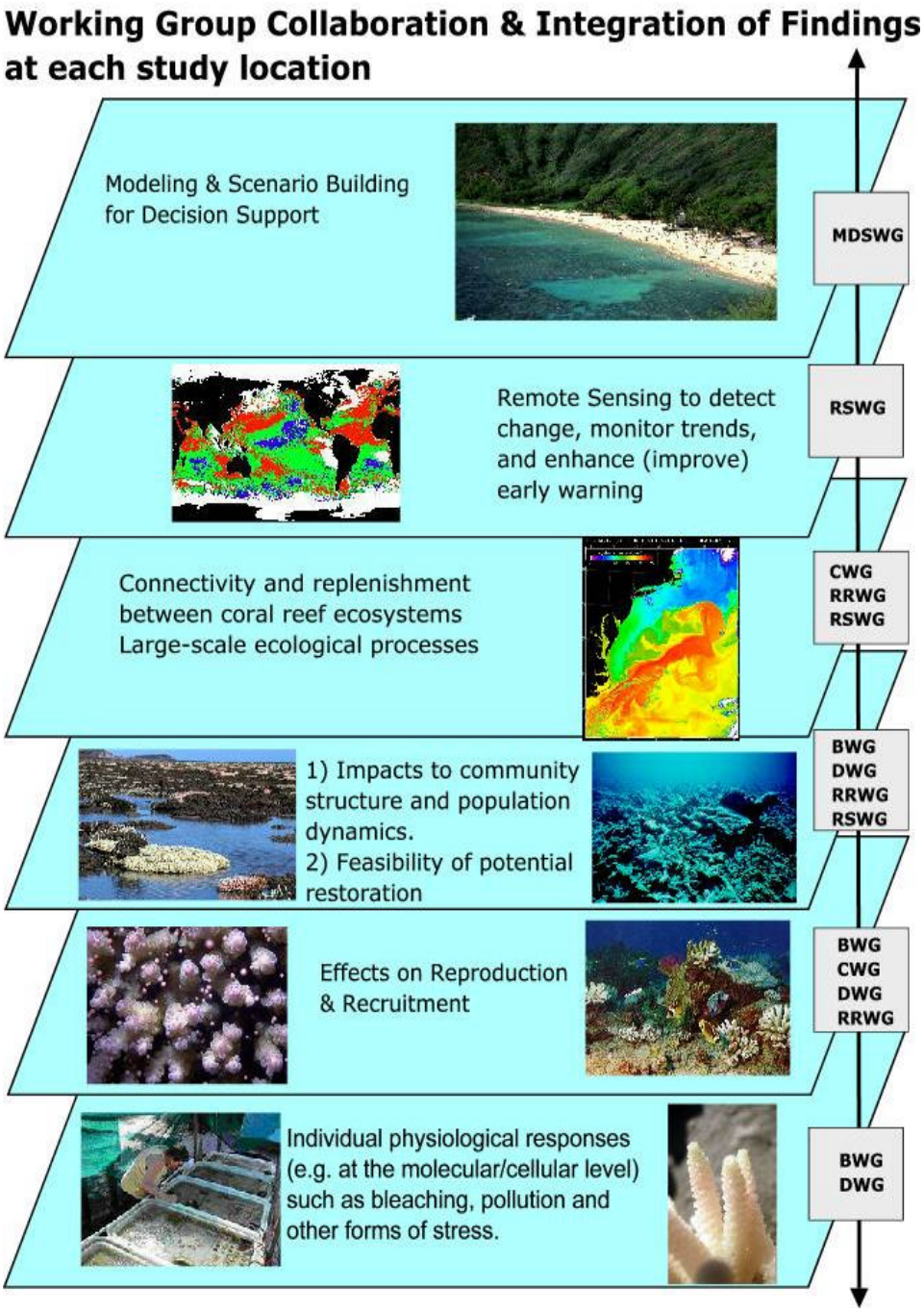

Figure1 - Major coral reef research themes and the integration of research across working groups. By employing this layering approach, there is greater leverage in relating information across themes and within the initially limited numberof studysites. Sites may increase in replication as this model evolves over the course of the Targeted Research program.

The project is organized around six key themes and research questions, which will be investigated by interdisciplinary teams of developing and developed country scientists. These themes were identified through extensive consultation over the course of project preparation to encompass the kinds of knowledge

and management tools that underpin sustainability science for coral reefs. They include:

i. The physiological mechanisms and ecological consequences of large area (or massive) coral reef bleaching, particularly in response to sea surface temperature anomalies, like the El Niño/Southern Oscillation episodes, and the potential consequences of their changes in frequency;
ii. The nature, severity and spread of coral reef diseases, some of which may be responsible for major shifts in the structure, function, health and sustainability of coral reefs;
iii. The importance of physical and biological connections (or "connectivity") between coral reefs, whether within or between different regions of International Waters. This also has direct bearing on the environmental conditions and key design factors needed to establish and sustain effective Marine Protected Areas (MPAs);
iv. The tools, technologies and efficacy of restoring coral reefs that have been severely degraded or destroyed, and the key organisms and environmental conditions to consider when rehabilitating a given coral reef environment;
v. The application of advanced technology, particularly remote sensing, to refine information and enhance the rate and scale at which knowledge can be generated and applied. This includes the need to modify technology so that it can be practically deployed and sustained within developing countries;
vi. The need to develop decision support tools and scenario building which integrate economic development with bio-physical and other forcing functions to determine coral reef ecosystem response to (different kind and rates of) change or stress. Included in this type of analysis may be the impact of human stress on altering trophic relationships on coral reefs, particularly the relationship between nutrients, overfishing, and the overgrowth of corals by seaweeds and the reversibility of transistions between coral dominated and algal-dominated states. Such models will incorporate the economic value of coral reefs, the socio-economic factors that affect the sustainable use of coral reefs, and the factors that inhibit translation of science into management.

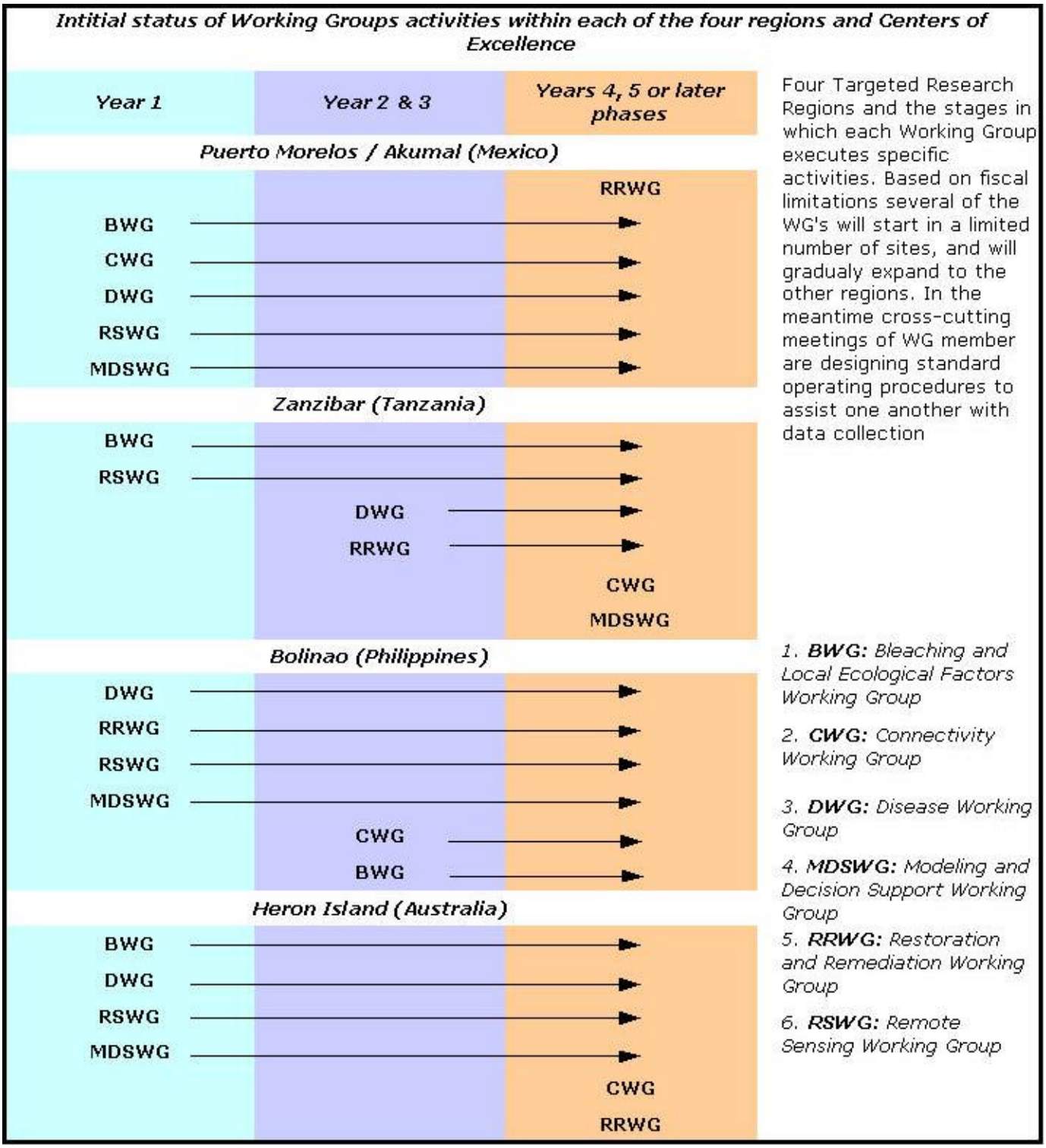

Figure 2 - Study Site locations and the stages at which working groups will engage.

b. Promoting Scientific Learning and Capacity Building

Currently, most coral reef research is based in universities and research institutes in the developed world, while most coral reefs are located in developing countries. Rectifying this global discrepancy is a key

mission of this project. To accomplish this, the research themes outlined above will be explored in different regions. This will serve both to ensure that the information ultimately used by managers is regionally appropriate, and to allow the training of local scientists so that they can respond to future developments.

The Targeted Research investigations will focus around four "Centers of Excellence" (COE) in four major coral reef regions (Western Caribbean (Universidad Autónoma Nacional de México), Eastern Africa (Marine Science Institute, Zanzibar, Tanzania), Southeast Asia (Marine Science Institute, University of the Philippines), and the central south Pacific (University of Queensland, Australia). These COEs will serve as nodes for targeted learning and capacity building between developed and developing country scientists.

Specific learning exchanges are already underway in which interdisciplinary teams of researchers have the opportunity to formally exchange ideas, and jointly implement research techniques and methods. Large-scale experimental designs also offer the opportunity to engage both researchers and managers in the design, testing and implementation of the priority, targeted experiments. Through twinning arrangements between various universities and research institutions, coral reef scientists from developing countries will exchange with partner institutions to learn cutting edge techniques in e.g., the identification of coral pathogens, measurements of metabolic stress linked to specific environmental stressors, the use of genetic markers to track larval dispersal and connectivity, and application of agent-based modeling techniques to simulate coral reef ecosystem response to various forms of stress.

The Targeted Research Project will support a series of workshops each year which will bring researchers in the various working groups together to orient field research, brief each other on findings and based on these results, modify and design the next phase of investigation.

c. Linking Scientific Knowledge to Management and Policy

A key outcome of this work will be to improve our predictive capability in assessing impacts to coral reef ecosystems, in the face of cumulative stress from increasing coastal populations, changes in climate and other uncertainty. These targeted investigations are being designed to feed into decision support systems for managers, policy makers, and other stakeholders.

The results generated from the targeted investigations will be formulated for various users. Over the course of project implementation, the information and tools produced will be disseminated as knowledge products to enhance the management of coral reefs. These products may range from in-situ diagnostics (for example, disease assessment and bio-indicators of specific forms of stress and metabolic response in coral reef organisms, to markers for larval recruitment indicating source and sink reefs) to remote sensing products and applications to assess the state of coral reef health. In addition to these tools, a series of management and policy briefs will be developed periodically by the Steering Committee and released to targeted audiences. These audiences include Bank Country Directors and Country Assistance Strategy (CAS) and Poverty Reduction Strategy (PRS) teams, GEF project teams, policy-makers, and member of regional and global fora (e.g, the IPCC, CSD, ICRI, SBSTTA, Regional Seas Conventions).

Links will be made between research results and management efforts in the four nodal regions. Each Center of Excellence will serve as the conduit of information to satellite sites and various user/stakeholder groups (including NGOs and others involved in MPA management, coastal zone management and marine regulation, national and community-based coral reef management activities, ecosystem monitoring efforts, etc. see Figure below.) NGOs active in the region, represent a particularly cost-effective means to communicate findings to managers and help convert them into low-tech solutions for direct

application to developing country management needs. These include tool kits for managers, such as the one TNC has prepared for building resilience into MPA design, as well as those involving bio-indicators to assess stress in key reef species. At the other end of the spectrum, high level audiences will be kept abreast of research findings through publications of each of the working groups (a list of those already out or in press since project preparation is available on request); through Steering Committee briefings, and in the form of periodic management and policy briefs (précis). The Project will also make use of the IW:Learn Project (a GEF/UNDP/UNEP/WB Knowledge Management Project for International Waters) to help disseminate research findings. Electronic fora and roundtable discussions focusing on key themes emerging from the targeted investigations may be supported through the IW:Learn Project and open to the relevant community of practice.

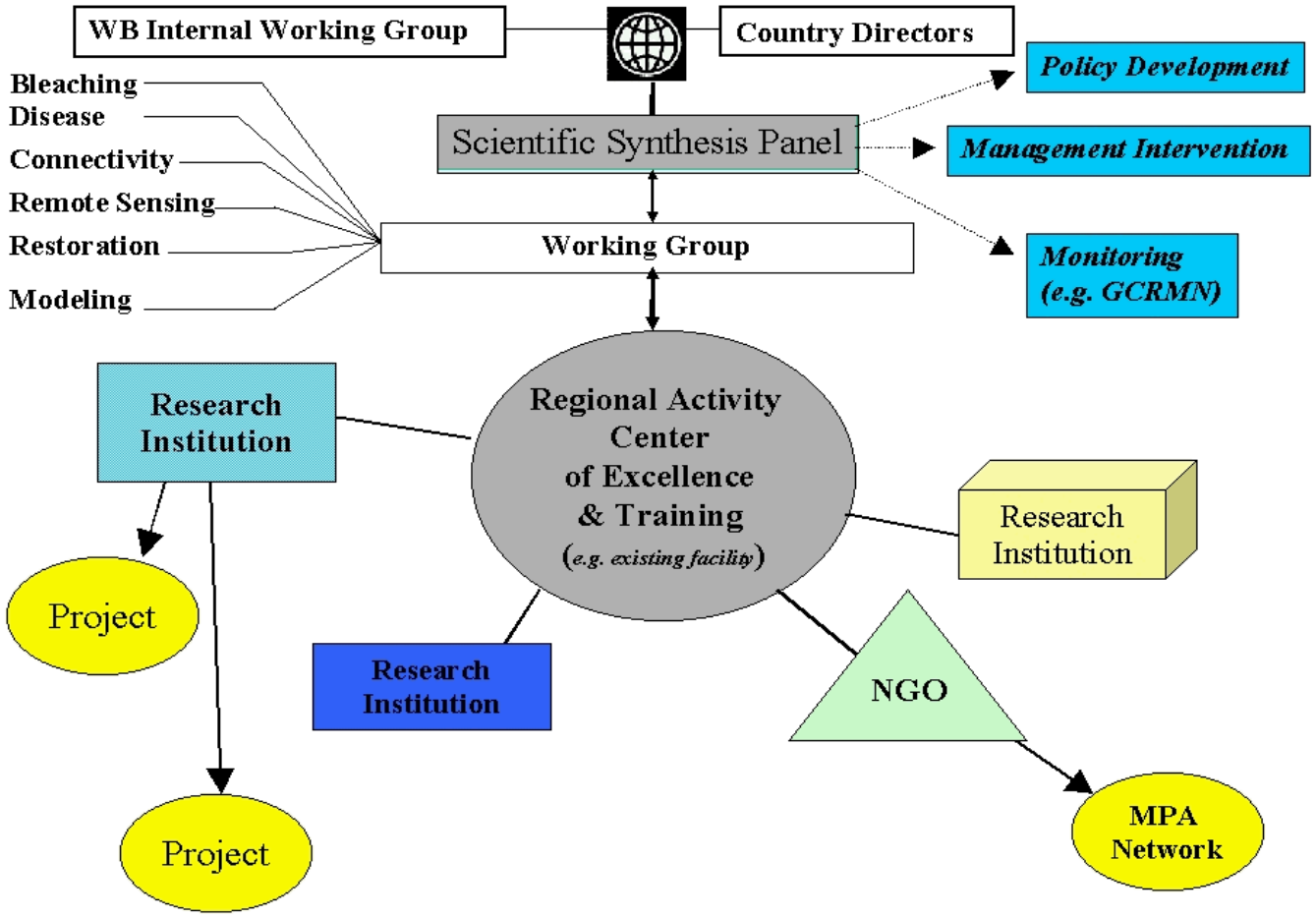

Figure 3 - Illustration of the institutional linkages involved in designing, implementing and disseminating the results of the targeted investigations. Institutional Nodes, or Centers of Excellence, will provide the quality control and research rigor required to carry out the experimental design formulated by the working groups and endorsed by the Steering Committee. Capacity building is the result of collaboration between a COE and other research facilities in selected locations with coral reef ecosystems, through formal exchanges, targeted learning and collaborative research. Research results are channeled to management projects and activities to inform decision making, and to policymakers to introduce needed reforms. Similar clusters of node and satellite institutions are envisioned in each region and some of the working groups may overlap in their use of field sites and clusters to carry out investigations.

Project Cost Table

Component	Indicative Costs (US$M)	% of Total	Bank and other co-financing (US$M)	% of Bank financing	GEF financing (US$M)	% of GEF financing
1. Knowledge & Technology Gaps	14.00	50.7	8.50	51.2	5.50	50.0
2. Promoting Learning and Capacity Building	6.00	21.7	3.00	18.1	3.00	27.3
3. Linking Scientific Knowledge to Management	4.10	14.9	2.10	12.7	2.00	18.2
4. Project Administration	3.50	12.7	3.00	18.1	0.50	4.5
Total Project Costs	27.60	100.0	16.60	100.0	11.00	100.0
Total Financing Required	27.60	100.0	16.60	100.0	11.00	100.0

Structural Elements

The primary structural elements are 1) six working groups organized around the research themes summarized above, 2) four regional nodes chosen to reflect the biological and cultural diversity of the world's reefs and to take advantage of existing local strengths, and 3) a Steering Committee, composed of the chairs of the six working groups plus additional outside experts, representatives of the four regional nodes, the “CEO” of the project responsible for implementing the Project (representing the executing agency), and a representative of the World Bank .

Working Groups

Working groups are arranged around the six research themes outlined above and composed of developed and developing country scientists from around the world. Each working group has developed a detailed work program (see Annex 2 for a detailed description of key hypotheses to be tested and criteria for priority setting) which has been reviewed by the Steering Committee. This work program defines the investigations to be carried out under Component 1. Research plans, standard methods and inter-institutional collaboration, including twinning arrangements for graduate students and post-docs between developed and developing country institutions, are being coordinated to maximize knowledge sharing and capacity building (see section 3 below). The working groups have prioritized questions to be addressed within each theme, through field-based hypothesis testing. The research questions and field locations have been organized so as to maximize synergies between groups and to produce a robust framework for the ongoing creation of knowledge and new tools essential for adaptive management of coral reefs. Knowledge will be disseminated widely and in a format useable by decision-makers.

Regional Nodes

Following extensive discussion by the Steering Committee, four regional nodes have been selected to reflect the biological and cultural diversity of coral reefs throughout the world, and centers of coral reef research which have (or may have) the capacity to serve as Centers of Excellence. Each of the working groups will conduct core elements of their investigations at at least two of the four regional nodes during the first five years of the Program. 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).

In each of the four areas, a regional activity and training center or COE has been identified:

- Western Caribbean: Universidad Autónoma Nacional de México
- Eastern Africa: Marine Science Institute, Zanzibar, Tanzania
- Southeast Asia: Marine Science Institute, University of the Philippines
- Central south Pacific: University of Queensland, Australia

These sites were selected on the basis of significant ongoing GEF and other donor 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 the research. It is the intent of the Project to build the capacity of the three developing country sites to help transform them into real Centers of Excellence for coral reef research.

The COEs will interact with other research institutions and NGO's in the area.

Current study site locations within each region include (i) the Mesoamerican Barrier Reef System (Puerto Morelos/Akumal, Mexico and Glover's Reef Marine Station, Belize), (ii) Bolinao (and the Hundred Islands), northwest Philippines, (iii) Zanzibar, Tanzania (iv) Papua New Guinea, (v) Heron Island, (vi) and Palau. Other potential locations, including sites in Indonesia, are also under consideration.

Steering Committee (a.k.a Synthesis Panel)

A guiding Steering Committee helps gives direction to the targeted research program (see Component 1) and ensures that the whole is greater than the sum of its parts. This Committee also serves as a formal interlocutor with other disciplines, such as development economics and law, to enhance the relevance and uptake of results by policymakers. It synthesizes and interprets results and modifies the focus of investigations as needed to benefit management and policy Examples include the development and dissemination of a series of management and policy briefs in a form easily internalized by several audiences (see Component 2.)

The Steering Committee consists of the heads of each of the six thematic working groups, representatives from each of the four regional nodes, the person from the implementing agency responsible for the day-to-day operation of the program, several outside experts representing coral reef scientists, economists, and managers, and a representative of the World Bank Group. One of the outside experts chairs the Steering Committee. Procedural details for the functioning of the Steering Committee will be developed prior to Project implementation.

2. Key policy and institutional reforms supported by the project:

Key Policy and Institutional Reforms

The key policy reforms to be sought will be (i) better information and knowledge transfer of those practices that can most effectively alleviate localized human stress that may contribute to increased vulnerability of coral reefs to the effects of climate change; (ii) development of institutional and human resource capacity to support coordinated, long-term investigations into the nature of stress/response interactions determining coral reef sustainability in the face of cumulative stress from natural and human-induced causes; (iii) facilitating the linkages between science and management to visualize future scenarios (e.g., of resource state and provision of goods and services) based on current patterns and trends, identify appropriate regulatory and incentive-based interventions, and build support for sustained conservation of coral reefs.

Although this framework is designed to address targeted research globally, the Project aims to shape policy

decisions affecting the sustainability of coral reef ecosystems at national and local levels. It aims to do this by developing accurate stress/response and ecosystem dynamic models and decision support that will significantly improve our understanding of coral reef ecosystem resilience, vulnerability to difference forms of stress (from local, human-induced stress, to climate change impact), and the steps that can be taken to reduce uncertainty in designing management interventions. Scenario building, which will allow the forecasting of reef ecosystem response to stress under different management/use options (including upstream or offsite development), will provide decision-makers with the basis for significantly improved management interventions and the design or strengthening of relevant policies that contribute to the sustainability of coral reef ecosystems for generations to come.

What is needed is a change in the way coral reef science is pursued in support of management and in the way development decisions which may affect coral reefs are made. This involves a commitment by the public sector to sustained, targeted and high quality empirical work directed at resolving key unknowns as a fundamental priority. Once these key, targeted gaps in knowledge are filled, the dissemination of this information to policymakers, the scientific community, industry, coastal managers and the general public will have positive impacts on management interventions and policy. Ultimately, the Targeted Research will support policies related to mitigating the causes and effects of climate change, improve those practices and technology that most effectively reduce land bases sources of pollution to reefs, over-fishing, and the application of tools to enhance natural resilience and recovery of reefs to stress. (This includes better zoning of coastal landscapes and seascapes, and terrestrial corridors contiguous with reefs, adoption of improved field techniques to assess reef health or factors such as disease, light, heat and other stressors which may elicit coral bleaching; or may facilitate artificial restoration.)

3. Benefits and target population:

Benefits and Target Population

The benefits of this project are primarily global, however, there will also be regional and local benefits as a result of many of the findings. The targeted research is directed at filling critical gaps in our understanding of how coral reef ecosystems around the world respond to different types of threats, how to mitigate these threats, and how best to enhance natural resilience to and recovery from major disturbances. Only with systematic investigations designed to identify the nature of ecosystem response to such threats and to discriminate significant trends in coral reef ecosystem response from natural variability (background noise), can science provide the guidance needed to managers and stakeholders who rely on coral reef ecosystem goods and services for livelihoods, or value their biological, cultural and intrinsic worth.

The major benefits of the TR will be:

- networks of developed and developing country scientists collaborating on the testing of strategic, priority hypotheses related to determinants of coral reef vulnerability and resilience under various forms of stress;
- capacity and long-term commitments for targeted learning within and across regions strengthened
- a rigorous framework in place for science based management of coral reef ecosystems in four key regions of the world;
- informed decision making backed by solid science that reduces uncertainty, and guidance to GEF and other partners on the range of options and most cost-effective investments to improve the condition of coral reefs globally.

Development benefits include a globally coordinated scientific community skilled in developing

investigative frameworks designed to reduce uncertainty regarding key issues related to ecosystem sustainability within and between regions, and to develop cost-effective tools and knowledge that will significantly improve coral reef management at the local level. Beneficiaries, therefore, include (i) the community of established coral reef scientists, who will have the opportunity to collaborate on a global scale on agreed priorities essential to effective, long-term management, (ii) the emerging generation of new coral reef researchers who will be trained in cutting edge investigative techniques by the best scientists in the field, to answer these and other questions, as they emerge, related to the survival of coral reef ecosystems, as we know them, around the world.

Managers (including public sector, NGOs, CBDOs and policy-makers will also benefit from this Targeted Research as the recipients of knowledge and key information that will help them make the case for better practices and policies aligned with conservation and sustainable use of coral reef ecosystems. The Targeted Research preparation has consulted extensively with on-going scientific and management efforts related to coral reefs. Current coral reefs management initiatives, such as ICRAN, which is now an operational network of ICRI, will benefit by strengthening management recommendation and options as a result of this project. NGO program, such as the Nature Conservancy's "Transforming Coral Reef Conservation for the 21st Century" will also use results, and is collaborating with this project to further conservation objectives. Important indirect beneficiaries are the hundreds of millions of people who either rely on coral reefs for environmental security and economic livelihoods; enjoy reefs for their recreational, cultural and spiritual value; or stand to gain from biodiversity and ecological services that have yet to be assessed.

The GEF and its implementing agencies, including the World Bank, will also benefit significantly from the guidance emerging over the course of this targeted research program, to assess the cost-effectiveness and long-term impact of current interventions and improve upon them; the need to re-orient strategic assistance, and how to achieve synergy across related focal areas (e.g., international waters, biodiversity and climate change).

4. Institutional and implementation arrangements:

A major study to identify the most appropriate institutional arrangements and flow of funds for the implementation of the project was commpleted as part of project preparation. The results of the study have recommended the establishment of a global implementing agency (the Project Executing Agency or PEA) with overall responsibility for project execution and administrative accountability to the Bank. The PEA must be established by a host organization that has global reach, is a leader in the field of coral reef research and management, and will be able to provide continuing management support. The host organization must have high standards of corporate governance and international recognition to ensure compliance with Bank and GEF fiduciary policies and be able attract other donor support. The management arrangements will facilitate rapid disbursement at the field level with several technical working groups working at a number of global locations.

A Steering Committee consisting of Technical Working Group Chairs and independent members will provide technical guidance to the PEA (see also section E.4). The themes to be addressed by the Technical Working Groups are selected by the Steering Committee, and the composition of Technical Working Groups is under the purview of each Working Group Chair. The targeted research will be implemented by scientists within these Technical Working Groups and will involve, whenever possible, the regional Centers of Excellence located the beneficiary countries.

The PEA will operate independently, but will receive guidance from the Steering Committee which will be responsible for reviewing the overall management of the project and performance of key project staff,

evaluating the existing funding situation and future prospects, and reviewing progress made towards both targeted research and capacity building in all Working Groups and Centers of Excellence.

The PEA will have a fully dedicated staff to oversee project implementation, outreach and communication activities, and future planning (including development activities to identify future co-financing and new partnerships). Such a staff will include, at a minimum, a senior level Executive Director, a Project Coordinator, an Outreach and Communications Specialist, and a Financial Manager. These will be full time positions, preferably working out of the same centralized project office. In addition, the PEA will hire, as necessary, short term consultants to 1) design workshops to integrate the research efforts of the Technical Working Groups, 2) oversee capacity-building efforts within the regions, and 3) disseminate synthesized results of targeted research to recipients involved in coral reef management, such as decision-makers, non-governmental organizations, and donor organizations.

In addition to the core management group that works together out of a centralized location, one or more data managers or data repository system, such as ReefBase, will be necessary. This person or persons will not only manage databases for the TR, but also develop and implement mechanisms for accessing such data -- for the scientists involved in the project (possibly through some sort of secure Intranet) and for the public at large. The need for such a position will of course increase through the life of the project. Staffing for this activity need not be housed in the PEA office, but rather could be at the site of the data repository.

The Technical Working Groups will be responsible for planning detailed research activities in each specialty, including choices regarding individual projects and institutions, as well as budgetary decisions involving resource allocations and procurements. Chairs of the Technical Working Groups will develop and submit annual work plans to the PEA, to be reviewed and approved by the Steering Committee. Each chair will also be responsible for evaluating progress made towards the stated goals of the Technical Working Group which he/she heads.

The PEA will receive scientific advice from the Steering Committee (and its sub-committees), which will convene (physically and/or electronically) regularly to review annual work plans, provide specific input to the PEA on integrative activities, and assess progress made towards the stated goals of the project. This Steering Committee will develop the big picture view of what is being learned through the targeted research, and will work to actively integrate the findings of the technically disparate working groups. The Steering Committee will also be responsible for identifying gaps in research that should be filled through adjustments of the plans of the Technical Working Groups, or by the addition of new working groups. As such, the Steering Committee will have responsibility for developing research plans for the second and third phases of the project, beyond the first tranche of funding. The Steering Committee will be served by the Project Executing Agency staff, including its Executive Director, Project Coordinator, and Outreach and Communications Specialist. More detail on institutional arrangements and flow of funds will be provided in a separate annex to the PAD.

D. Project Rationale

1. Project alternatives considered and reasons for rejection:

The global knowledge creation and capacity building that is part of this program is consistent with the GEF's new strategic emphasis on targeted learning to build indigenous capacity within its clients for strategic and effective environmental decision-making. The Targeted Research is the first full size project for Targeted Research in the IW Focal Area to be presented to the GEF. It is innovative in its approach to build this capacity by creating networks of the best scientists in the developing and developed world to

collaborate on key questions of global concern, include young professionals in the fieldwork and formal degree level training associated with the research and, through such north-south/south-south partnerships, establish centers of excellence for coral reef research and management in strategic locations coinciding with the distribution of major coral reef ecosystems. The nature of this cross regional/global approach necessarily involves incremental costs which must be borne by facilities such as the GEF and other stakeholders in the marine conservation community.

Previous studies of large-scale environmental impacts have already shown that organizing response, damage assessment and restoration programs in a reaction-based model results in significant financial and societal costs to both the affected and responsible parties. Alternatively, this approach suggests a proactive model to prioritize and target specific investigations that can plan for and hopefully intervene with management alternatives in anticipation of future environmental impacts and stresses. This approach can have valuable implication for both governments and industry, so that future actions can focus on preventative interventions, rather than curative ones.

An alternative to this approach is the no-project alternative, which would perpetuate the problems of uninformed/reactive management rather than science based/pro-active management, and isolated, country-specific research. The latter which, while valuable, would not have the spin-off and global learning impact of the networked research and integrated problem solving that is the hallmark of this Targeted Research and Capacity Building Program.

2. Major related projects financed by the Bank and/or other development agencies (completed, ongoing and planned). Please refer to the Map annex to see where many of these Projects are located in relation to the Centers of Excellence.

Sector Issue	Project	Latest Supervision (PSR) Ratings (Bank-financed projects only)	
		Implementation Progress (IP)	Development Objective (DO)
Bank-financed			
Improving management of highly threatened, economically important environmental goods and services in the epicenter of marine biodiversity.	Coral Reef Rehabilitation and Management Project (COREMAP): Phases I-II	S	S
	Conservation and Sustainable Use of the Mesoamerican Barrier Reef System	S	S
	Gulf of Aqaba Environmental Action Plan	S	S
	Red Sea Strategic Action Plan Implementation (Bank, UNEP and UNDP)	S	S
	Coral Reef Monitoring Network in Member States of the Indian Ocean Commission (COI), within the Global Reef Monitoring Network (GCRMN)	S	HS
	Coastal and Marine Biodiversity Management	S	U

	Project, Mozambique Coastal and Marine Biodiversity Conservation in Mindanao, Philippines Marine Biodiversity Protection and Management (MSP), Samoa Hon Mun MPA Pilot Project (MSP), Vietnam CORALINA Project, San Andres, Colombia Coastal Zone Integrated Management Program, Benin (Pipeline) Guinean Coastal Zone Integrated Management and Preservation of Biodiversity (Pipeline) Coastal and Biodiversity Management Program, Guinea Bissau (Pipeline) Marine and Coastal Biodiversity Conservation, Senegal (Pipeline) Sustainable Coastal Livelihoods, Tanzania (Pipeline) Mainstreaming Adaptation to Climate Change in Caribbean (Pipeline)	U S HS HS	S S S HS
Other development agencies Selected UNDP Activities	Tanzania: Development of Mnazi Bay Marine Park Comoros: Conservation of Biodiversity and Sustainable Development in the Federal Islamic Republic of the Comoros Mauritius: The Management and Protection of the Endangered Marine Environment of the Republic of Mauritius India: Management of Coral Reef Ecosystem of Andaman and Nicobar Islands Maldives: Conservation and Sustainable Use of Biodiversity		

	Associated with Coral Reefs in the Maldives		
	Vietnam: Coastal and Marine Biodiversity Conservation and Sustainable Use in the Con Dao Islands		
	Philippines: Conservation of the Tubbataha Reef National Park		
	Philippines: Biodiversity Conservation and Management of the Bohol Islands		
	Papua New Guinea: Milne-Bay Province Marine Integrated Conservation		
	Belize: Conservation and Sustainable use of the Barrier Reef Complex		
	Cuba: Priority Actions to Consolidate Biodiversity Protection in the Sabana-Camaguey Ecosystem		
UNEP Activities	Reversing Degradation Trends in the South China Sea and Gulf of Thailand		
	Integrating Watershed and Coastal Area Management in Small Island Developing States of the Caribbean		
	Development and Protection of the Coastal and Marine Environment in Sub-Saharan Africa		
	Reduction of Environmental Impact from Tropical Shrimp Trawling through Introduction of By-catch Technologies and Change of Management		
Other Donors	International Coral Reef Initiative (ICRI)		
	International Coral Reef Action Network (ICRAN)		

IP/DO Ratings: HS (Highly Satisfactory), S (Satisfactory), U (Unsatisfactory), HU (Highly Unsatisfactory)

3. Lessons learned and reflected in the project design:

Historically, research components of GEF projects dealing with coastal and marine ecosystems have focused on assessing and monitoring baseline conditions. Several have documented declines in the resource base, but few, if any, have supported experimental research that would improve our understanding of ecosystem function or factors that regulate ecosystem response to various kinds of threats. A recent Consultative Group meeting of the WB/GEF MesoAmerican Barrier Reef System Project held in Belize (October 03), flagged the Targeted Reseach Project as a much needed complement to the work the MBRS Project is undertaking in sustainable fisheries, monitoring of ecosystem health and policy harmonization in coral reef related sectors in the four participatin countires. This includes: (i) managing spawning aggregations of commercially valuable reef fish (and links to the TR Connectivity Working Group), (ii) implementing the first regional Synoptic Monitoring Program of Reef Health for the MBRS (with links to the TR Remote Sensing Working Group and to the the Disease and Bleaching Working Groups); and (iii) technical input to the MBRS Policy Woking Groups on harmonizing policies and good practice related to shared resources of the MBRS (with links to the TR Modeling and Decision Support Working Groups). Similarly, the COREMAP II Project Team and NGOs (TNC) working alongside, have indicated very strong interest in collaboration with the TR Working Group on Reef Restoration and Rehabilitation, to test new tools for restoring dynamited and cyanide damaged reefs in the region. Given the emphasis on ecosystem-based management endorsed by the GEF, the WSSD and others for favoring a holistic approach to natural resources management, there is a need to understand the nature and pathways of ecosystem drivers to identify bottlenecks in ecosystem function and how best to address these.

Lessons learned from past experience with public sector financed-research have been incorporated into the design of the Targeted Research, as follows: (i) target research on strategic priorities which will significantly enhance knowledge required for effective management, (ii) identify near-to-medium term products and tools that can be applied in the interim to demonstrate the benefits of a committed, targeted research program; (iii) ensure transparency and full-fledged participation in partnerships between developed and developing countries, and (iv) disseminate knowledge as widely as possible, taking care to tailor messages to different target audiences.

Historically, the coral reef scientific community has been fragmented in its approach to conducting investigations in a coordinated manner, and over both space and time. The TR framework presents the first opportunity for the coral reef scientific community to pool its intellectual resources and energies—in a collaborative mode with developed and developing country scientists—to design targeted investigations that will address key unknowns and ultimately contribute to improving human welfare. The research framework has emphasized the need to prioritize gaps in knowledge, sequence investigations to build on knowledge obtained by one or more working groups, analyze and synthesize results (with the help of the Steering Committee), and disseminate these as discrete knowledge products and innovative tools to stakeholder groups. As the results from these investigations come on line, the Steering Committee will be in a position to collectively address how the information may best be used to affect management options, influence policy, contribute to the accuracy of economic models involving coral reefs and dependent communities, and improve the quality of life through enhancing the sustainability of strategic resources.

4. Indications of borrower and recipient commitment and ownership:

This project is global in scope, and will involve more than 70 international scientists and a host of scientific institutions from around the world. The proposal has the strong support of the nodal agencies in the four countries involved (Mexico, Tanzania, the Philippines and Australia), as evidenced by the letters of endorsement from these institutions. The coral reef community in these and other countries in the regions who will benefit from direct involvement in the research or from the management information that will be generated by it are also enthusiastic about this global effort. A strong role for the COEs is envisioned in terms of engaging other institutions in the region in the research, building capacity among the next generation of coral reef scientists and serving as an information clearing house to a range of stakeholders (from local communities to national and regional level policy-makers). These activities are consistent with the missions of the COEs, and their roles in providing technical advice for the formulation of national and regional policies. To create local buy-in, each Center of Excellence will serve as the conduit of information to satellite sites and various user/stakeholder groups and projects within each region. NGOs active in the region will help to communicate findings to managers and help convert them into low-tech solutions for direct application to developing country management needs. These include tool kits for managers, such as the one The Nature Conservancy has prepared for building resilience into MPA design, as well as those involving bio-indicators to assess stress in key reef species.

5. Value added of Bank and Global support in this project:

Of the 184 member countries of the World Bank, more than 90 countries rely on coral reefs as natural economic assets. However, most of these reefs and associated resources are components of larger transboundary marine ecosystems, which require multi-country approaches to manage and conserve. The Bank has considerable experience in transboundary water resources management through a growing portfolio of Regional Seas and International Waters programs. More recently, experience in promoting regional cooperation in the conservation and sustainable use of the world's second longest barrier reef system—the Mesoamerican Barrier Reef System—has provided a model for regional coordination, involving multinational technical and policy working groups, on which the TR Project can build.

The Bank is in a unique position to provide global leadership on needed policy reforms that may be implicated by the TR findings. World Bank Country and Sector Directors will be apprised periodically of the research results and their implications for the Bank's clients, by an internal Project working group of Bank Task Team Leaders of coastal and marine resource management projects. Result can form the basis for ESW, flagging the value of goods and services provided by coral reefs and what is at stake, or feed directly into the Country Dialogue with clients with coral reefs, and the Country Assistance Strategy and the PRSP process. Where appropriate, new investment projects may be identified to reduce stress on coral reefs and the threat to reef-dependent communities, as in Tanzania, where a Sustainable Coastal Livelihoods Projects is being designed as a follow up to the PRSP.

E. Summary Project Analysis (Detailed assessments are in the project file, see Annex 8)

1. Economic (see Annex 4):

○ Cost benefit NPV=US$ million; ERR = % (see Annex 4)
○ Cost effectiveness
● Incremental Cost
○ Other (specify)

The activities and costs subsumed under this Project are entirely incremental, as they support global learning and capacity building for science-based decision-making. Baseline research activities in client counties consist mostly of coral reef monitoring and localized investigations. Apart from monitoring

activities, these efforts are not systematically networked at the national or regional level, nor are they designed to shed light on specific stress response relationships, or the variability in response (i.e., in resilience or vulnerability) that reef ecosystems may display depending on the type, intensity and cumulative nature of the stress. In contrast, the GEF Targeted Research Project is designed to focus on strategic questions directly related to the sustainability of coral reef ecosystems at different sites, under varying stress regimes, and to compare these results across regions. The interdisciplinary nature of the working groups, the geographic and temporal scale of the research program (across four distinct coral reef regions, over 15 years), and the networked nature of the research, will require a degree of cooperation and support that cannot be sustained by any one country. The transboundary nature of coral reef ecosystems, the threats to their sustainability, and the fundamental gaps in our understanding of system behavior and recovery potential, require a multinational effort that spans a range of variability within and between systems. Multinational working groups and cross regional learning and capacity building will ensure that this is a truly global effort, extending well beyond the boundaries of the research sites and countries involved.

No other organization is presently undertaking such a coordinated and targeted program of research to inform managers and policymakers on cost-effective options for coral reef conservation and management. This program would simply not be possible without GEF funding. The GEF serves as an organizing force around which a significant proportion of the community of practice for coral reef research is being united for the first time. The preparation activities have galvanized partner participation, and have resulted in resources and efforts to be realigned, but the GEF support will be catalytic in launching this Targeted Research. The GEF will also serve as a powerful catalyst to leverage funds from an array of partners and collaborators who are committed to supporting one or more aspects of the research. The critical mass of investigators and supporting institutions who are being brought together as a result of this initiative will have an unprecedented impact on the way ecosystem research is conducted in the future.

An incremental cost analysis has been prepared and is attached as Annex 4. The total Project Cost is estimated at US $28.8 million. GEF is asked to contribute $11 million, or approximately half the cost of implementing this first phase of the overall Targeted Research Program. Over $12 million has been identified as in-kind co-financing, and at least $5 million in cash co-financing is being sought from a number of sources to implement the work program presented here. These include: collaborating research institutions such as the University of Queensland, US NOAA and the University of Exeter, as well as from Foundations, Bilaterals and Trust Funds. In addition to cash, participating research institutions are expected to contribute substantial in-kind resources, in terms of access to field laboratory facilities, services, and staff time. The team is approaching a number of Private Foundations, which have specific programs for marine conservation, scientific research or climate change, as well as corporations with an interest in promoting marine tourism and travel. The latter have already pledged significant in-kind co-financing in the form of reduced hotel and air fares for Project researchers. Preliminary discussions within the Bank indicate strong interest and the possibility for co-financing from the Development Grant Facility, which has partnered with the GEF in the past (e.g., through the Critical Ecosystem Partnership Fund) and from Bilaterals with ongoing coral reef programs (e.g., Australia and Japan). Working Groups have also been seeking co-financing directly through national research funding agencies and collaborating institutions (e.g., US NOAA). An additional $10-20 Million in leveraged cash and in-kind resources (including personnel and equipment), not directly under the Project's control, will be raised from collaborating institutions. New partnerships are expected to emerge once GEF financing is committed and the Project gains momentum on the ground. (see section on Finance below).

2. Financial (see Annex 4 and Annex 5):
NPV=US$ million; FRR = % (see Annex 4)

The Project Executing Agency shall be the principal recipient of GEF funds, other donor funds and funds to be contributed by the participating governments. The PEA shall be fully accountable for all project funds and shall ensure timely disbursement of funds to participating project implementing institutions. PEA shall be responsible overall project management and coordination including procurement, financial management and project administration. Figure 4, below, illustrates one Flow of Funds Model based on existing Bank programs, to accommodate the diverse source of funds and the potential for new co-financing expected to emerge throughout Project implementation. This includes establishment of a multi-donor Trust Fund, administered by the World Bank, which can receive funds from a variety of donors to support agreed Project objectives, and may even accommodate earmarking for specific Project components in some cases. The financial management and reporting aspects of the Project will be described in Annex 6.

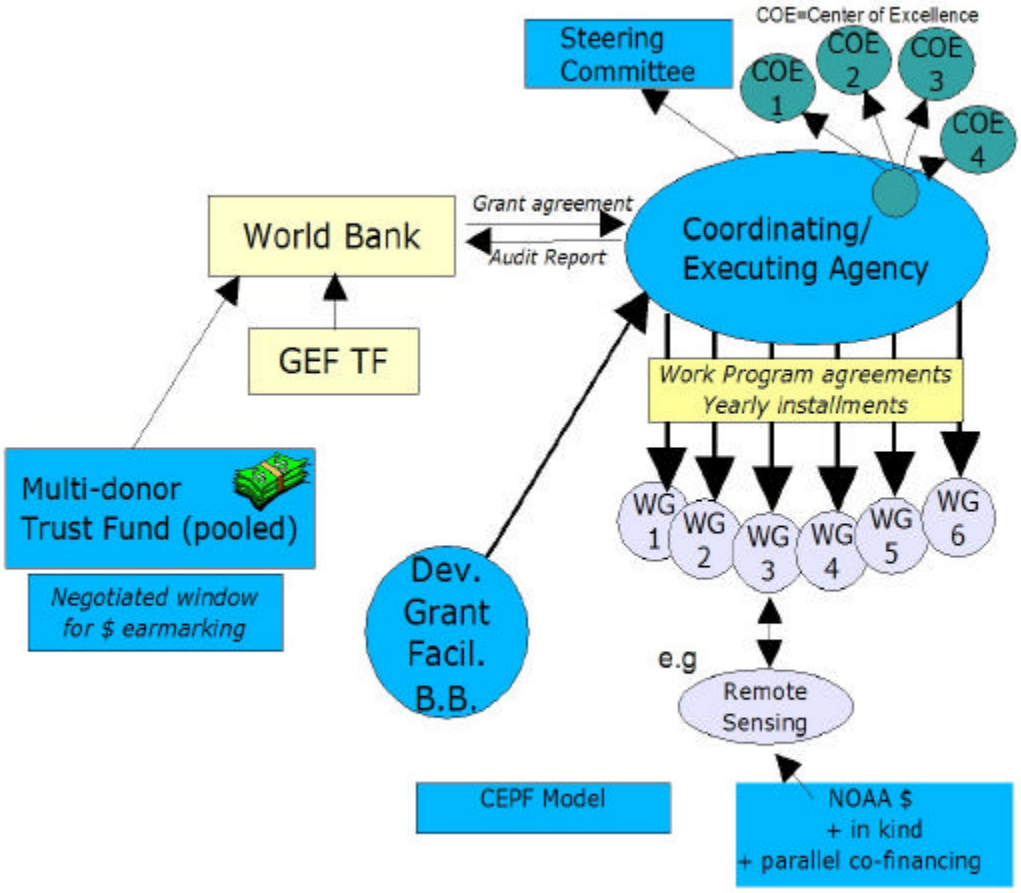

Figure 4 - Diagram of Funds Flow Model for the Targeted Research.

Fiscal Impact:

N/A (no loans involved)

3. Technical:

The six targeted research working groups will coordinate investigations and results through use of complementary study designs and locations, and through targeted learning exchanges. By coordinating the targeted investigations, the working groups are building an information base that can directly relate findings across space and time (see Figure 1). Such complementary data collection not only strengthens

findings but also enhances correlations at different spatial scales. Investigations within many of the Working Groups will also contribute to specific model development to support their respective areas of inquiry, and to contribute to the decision support. The standard operating procedures developed under the Project will contribute to more effective technical exchange by ensuring consistent application of methods and protocols. This has tremendous implications for extending technical capacity and standard approaches within the client countries. Combined with targeted learning exchanges, this technical approach allows a broad spectrum of researchers within both developed and developing countries to present and debate relevant issues about priority hypotheses, the logistics required to implement targeted research, and to share various experiences. This model is proving to be highly effective in knowledge sharing, and in transcending previous communication barriers. While certain locations will continue to experience limitations in infrastructure (i.e. Internet throughput--which is largely based on given Country's telecommunications infrastructure), these focused exchanges will help to mitigate this constraint within Centers of Excellence in each region.

In concert with the Synthesis Panel, the working groups members and supporting staff will design, plan and disseminate policy briefs and guidelines for the application of relevant findings into management and policy operations. These will be made available directly to clients, Bank country teams and sector units, the GEF, NGO community and to relevant international fora.

4. Institutional:

The Institutional and financial arrangements for the project are being finalized with the help of a team of consultants tasked with evaluating various models and options to administer a project of this scope. The team examined the qualifications of a number of candidates to handle overall administration of the project, including assessing their ability to provide intellectual leadership in facilitating the integration of the targeted research into the research agendas of the Centers of Excellence, strengthening their capacity to support international research and provide training in the region, as needed. Related to this, is the ability to manage knowledge, including the processing and exchange of information between regions and the dissemination of findings to appropriate user groups (e.g., managers, NGOs, policymakers, the general public). Careful consideration has also been given to various flow of funds models to arrive at the most efficient and transparent arrangements for timely disbursement to research teams, and accountability for funds (see figure in Section E.2).

4.1 Executing agencies:

Project execution will be carried out through a series of mutually reinforcing institutional arrangements. A partnership arrangement between the University of Queensland, Australia and UNESCO-IOC, has been determined to offer an optimal combination of financial accountability, technical expertise, capacity building and long-term institutional commitment (including substantial co-financing), to serve as the global executing agency. At the field site level, four nodal agencies will be responsible for hosting the research, helping to organize training workshops and information outreach activities. They will work closely with the 6 scientific working groups, who will be directly in charge of organizing and leading the research program. Liaison with local and international NGOs with projects in the region, and with other projects and research institutions who have expressed interest in collaborating in some aspect of the TR Program will be facilitated through this layered structure of project execution.

As a result of the Block A consultations which engaged both scientists and managers, a conscious decision was made to limit the research to 3-4 key coral reef regions of the world during the initial five year phase. These regions were selected on the basis of where there were already significant GEF and other investments in coral reef management; where there was the beginning of a critical mass of coral reefs scientists and

infrastructure to support establishment of a regional node (which could evolve into a Center of Excellence for coral reef research), and with support from the Project could facilitate research and capacity building at a number of satellite sites. The research nodes in these regions were carefully selected in coral reef ecosystems where considerable baseline data was already available and where resident researchers were engaged in research that could both contribute to and benefit from the targeted research objectives.

Under ideal circumstances and significantly larger financial resources, this project would have greater spatial replication and site representation within each of the regions identified, and would reflect some sort of stratified random sampling design. However, there will never be enough financial resources to conduct the kind of spatial replication that would be required to generate rigor and power in a statistical context (i.e. drawing inference over a sampling universe within a given region). As an alternative, this project has approached the targeted research with a case-study model, whereby a limited number of study sites have been identified, in which a suite of investigations around key themes is carried out and the information integrated at each site. Results will be compared across sites, where possible, to assess what impact/response relationships may be global in scope as opposed to regional (in terms of cumulative impacts) or even local in scope. It is legitimate and necessary to focus at the outset on a smaller number of sites until the effectiveness of the research model(s) can be demonstrated.

It is the project's intention to expand the number of sites as the Project progresses through successive phases and the working groups move toward filling critical information gaps through time. This is why the Targeted Research has been conceived as a 15 year program. Sequencing is essential in light of the human and financial resources available and to allow consolidation of results and reformulation of hypotheses before expanding into new regions and sites. (See Figures 1 and 2)

4.2 Project management:

Day to day administration of the TR Project will be the responsbility of the Project Executing Agency (PEA). The PEA will have a fully dedicated staff to oversee project implementation and performance, outreach and communication activities, and future planning (including development activities to identify future co-financing and new partnerships). Such a staff will include, at a minimum, a senior level Executive Director, a Project Coordinator, an Outreach and Communications Specialist, and a Financial Manager. These will be full time positions, preferably working out of the same centralized project office. In addition, the PEA will hire, as necessary, short term consultants to 1) design workshops to integrate the research efforts of the Technical Working Groups, 2) oversee capacity-building efforts within the regions, and 3) disseminate synthesized results of targeted research to recipients involved in coral reef management, such as decision-makers, non-governmental organizations, and donor organizations.will liaise with all of the Technical Working Groups, regional Centers of Excellence, and individual project staff when necessary.

The PEA will receive technical oversight and programmatic direction from a Project Steering Committee (aka the Synthesis Panel) consisting of the chairs of the 6 Working Groups, and 5-6 other professionals, including a representative of the World Bank (the Task Team Leader or her designee). The PEA will report formally at least once a year to the full Project Steering Committee. Sub-committees of the Steering Committee, focusing on Scientific Research, Capacity Building, and Information Synthesis and Outreach, will provide added guidance to the PEA (see below). In addition to the standard reporting (financial, technical progress, audits and annual work plans submissions) by the PEA to the Bank, the Bank will provide financial and technical oversight through supervision missions and an internal Bank Working Group, consisting of staff with relevant projects in the regions served by the TR Project.

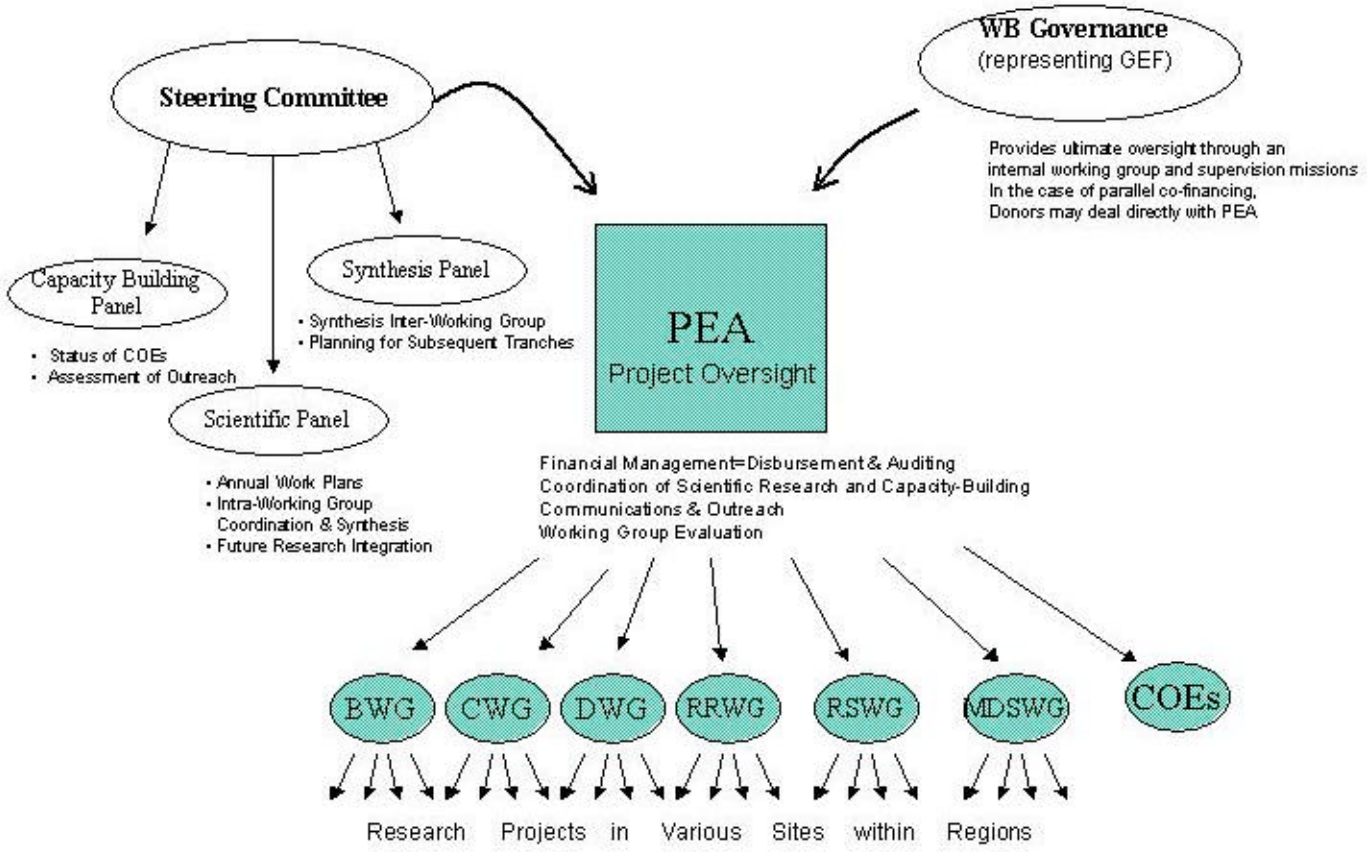

Figure 5 - Instituitional Arrangements for the Targeted Research Project

Project Monitoring and Evaluation

Project monitoring and evaluation will be the shared responsibility of the Project Executing Agency and the Steering Committee. M&E of progress by the Working Groups and Centers of Excellence will be an ongoing task of the PEA, whose responsibility includes reviewing budgets against agreed workprograms and outputs, reflected in the Project Performance indicators in the Log Frame. Chairs of the Working Groups will develop and submit annual research work programs to the PEA, to be reviewed and approved by the Steering Committee. Each WG chair will also be responsible for evaluating progress made towards the stated goals of the Technical Working Group which he/she heads. The full Steering Committee will convene (physically and/or electronically) at least once a year, and subcommittees more frequently if necessary, to review annual work plans, provide specific input to the PEA on integrative activities, and assess progress made towards the stated goals of the project, using perfomance criteria in Annex 1. Major discrepancies or inadequate progress would be documneted in the minutes of the meetings and in semiannual progress reports to the Project Steering Committee, which will have responsibility for approving the following year's research work program and budget for each of the six working groups and the four COEs. The scientific output of the Project will be continuously evaluated through publications in peer reviewed journals and presentations at international fora. An independent evaluation of the PEA and the Project's performance in achieving strategic goals and objectives will be carried out in Project Year 4. It is not feasible to do this any earlier, given the nature of scientific research and the time required to get

meaningful results with some degree of reliability. The independent evaluation in Year 4 will serve to determine whether a second phase of the Targeted Research Program is justified, and if so, how it should be structured.

4.3 Procurement issues:

See Annex 6.

4.4 Financial management issues:

These are discussed in the section on Financial Management arranagements in Annex 6.

5. Environmental: Environmental Category: C (Not Required)

5.1 Summarize the steps undertaken for environmental assessment and EMP preparation (including consultation and disclosure) and the significant issues and their treatment emerging from this analysis.

The Project is designed to enhance environmental sustainability. There are no negative environmental issues/impacts associated with this project. It is primarily a technical assistance project to build capacity for science based management of coral reef ecosystems. The approach is one of trying to create the investigative framework that will help reef scientists and managers understand the basis for ecosystem vulnerability or resilience in the face of key environmental stressors, such as climate change, land-based sources of pollution, disease, etc., and to develop tools that may be most cost-effective in reducing risk and enhancing sustainability. A Category C Environmental Rating has been assigned to the Project by the Bank's Environmental Safeguards Team.

5.2 What are the main features of the EMP and are they adequate?

n/a

5.3 For Category A and B projects, timeline and status of EA:
Date of receipt of final draft:

n/a

5.4 How have stakeholders been consulted at the stage of (a) environmental screening and (b) draft EA report on the environmental impacts and proposed environment management plan? Describe mechanisms of consultation that were used and which groups were consulted?

n/a

5.5 What mechanisms have been established to monitor and evaluate the impact of the project on the environment? Do the indicators reflect the objectives and results of the EMP?

n/a

6. Social:

6.1 Summarize key social issues relevant to the project objectives, and specify the project's social development outcomes.

Building capacity for science-based management of coral reefs in countries where they occur will increase the potential for appropriate and cost-effective management interventions, heighten accountability to the public re: important conservation/development tradeoffs and create the basis for risk management in the context of environmental uncertainty. All of these outcomes have substantial social benefits, particularly for those communities dependent on coral reefs. For tourism dependent countries, strengthening the information base to safeguard coral reefs will have enormous economic benefits as well.

6.2 Participatory Approach: How are key stakeholders participating in the project?

Participation of stakeholders will be via workshops, collaborative research, exchange of graduate students and post-docs, publications, symposia and application of research results to policy and management of coral reefs.

6.3 How does the project involve consultations or collaboration with NGOs or other civil society organizations?

The results of the research will feed directly into a variety of management activities already in place. Many of these are sponsored by NGOs and CBOs, working with communities to conserve coral reefs and ensure their continued production of environmental goods and services (see figure 1 in C). Among the NGOs with which the Project will be working are: The Nature Conservancy, Conservation International, WWF, The Wildlife Conservation Society, Environmental Defense, Centro Ecológico Akumal, Western Indian Ocean Marine Science Association (WIOMSA), Society for the Conservation of Reef Fish Spawning Aggregations (SCRFA); The project will also work with NGOs to disseminate information, educate the general public and provide material for their advocacy work for marine conservation.

6.4 What institutional arrangements have been provided to ensure the project achieves its social development outcomes?

The Synthesis Panel will serve as the interface between science and management and science and policy. The SP will ensure that research is carried out in a cost-effective and rigorous way to ensure credibility of results, and will channel findings to various stakeholder groups in appropriate formats to promote the visibility and uptake of the results in decision-making.

6.5 How will the project monitor performance in terms of social development outcomes?

This will be worked out in project preparation.

7. Safeguard Policies:

7.1 Are any of the following safeguard policies triggered by the project?

Policy	Triggered
Environmental Assessment (OP 4.01, BP 4.01, GP 4.01)	○ Yes ● No
Natural Habitats (OP 4.04, BP 4.04, GP 4.04)	○ Yes ● No
Forestry (OP 4.36, GP 4.36)	○ Yes ● No
Pest Management (OP 4.09)	○ Yes ● No
Cultural Property (OPN 11.03)	○ Yes ● No
Indigenous Peoples (OD 4.20)	○ Yes ● No
Involuntary Resettlement (OP/BP 4.12)	○ Yes ● No
Safety of Dams (OP 4.37, BP 4.37)	○ Yes ● No
Projects in International Waters (OP 7.50, BP 7.50, GP 7.50)	○ Yes ● No
Projects in Disputed Areas (OP 7.60, BP 7.60, GP 7.60)*	○ Yes ● No

7.2 Describe provisions made by the project to ensure compliance with applicable safeguard policies.

N/A - this is a technical assistance project focused on targeted research and learning. None of the activities identified under this project are likely to trigger any of the Bank's Safeguard Policies.

F. Sustainability and Risks

1. Sustainability:

The Project is envisioned as the first phase of a long –term effort which will be sustained through a coalition of partners, built around a common agenda and measurable outcomes. GEF support is only being requested for this initial phase, which will serve as a proving ground for the targeted research model and a platform for scaling up and replicating the model in subsequent phases. However, the requested level of GEF support in this early phase is critical in that it will serve as the primary catalyst to (i) build a broad coalition of partners (within the scientific, NGO and management communities) committed to this effort over the long term, (ii) mobilize the necessary human and financial resources to undertake it, (iii) re-align ongoing and potential investments of partners in a coordinated effort that will bring focus and cutting edge science to a common research agenda, and (iv) facilitate the uptake of new knowledge and tools derived from the targeted research into the design and implementation of GEF-supported activities related to coral reefs.

A long-term approach is needed because coral reefs are influenced by processes over a wide range of temporal and spatial scales. Research in other marine environments has consistently identified the need to establish long-term studies and management trials (over at least 10 to 15 years) to better understand the dynamics and drivers of these systems. This is especially true of coral reef ecosystems. Existing research indicates that coral reefs fluctuate on several decade-long time scales, hence the need to sustain this effort over a multiple phases. The results generated have the potential to eliminate much of the uncertainty characterizing coral reef management efforts to date and to transform management of highly threatened ecosystems from a reactive, empirical mode to a pro-active one. This has important implications for resource allocation, with a focus on preventive measures to manage risks to coral reefs.

Despite the long-term nature of these investigations, information products will be staged for delivery at periodic intervals to provide interim benefits and tools for managers. This will help sustain the commitment that will be required to reap the benefits of targeted investigations over the longer term. As this program of research develops, the Centers of Excellence become stronger, and the working groups generate visible benefits for management and policy, it is hoped that the project's partnerships will expand and that additional financing from research institutions, governments and private foundations will be forthcoming, eliminating the need for further GEF support. Linking the TR to Bank investments, as in Phase 2 of the Indonesia Coral Reef Rehabilitation and Management Project (COREMAP, which includes GEF support) and to a Poverty Reduction Strategy Credit for Sustainable Coastal Livelihoods in Tanzania, will contribute the sustainability of the TR and the uptake of results in follow-up actions.

GEF support during preparation and the promise of support for this initial phase have been absolutely essential to securing the buy-in of key partners thus far. In addition to the direct Project co-financing, significant investments in related activities have also been **leveraged**, to coincide with this initial phase of the Project. While these leveraged investments lie outside the Project, the results will contribute important knowledge toward filling gaps and strengthening networking with scientists engaged in the Targeted Research, thus also contributing to capacity building. Extending the TR effort to subsequent phases will depend on the success of this initial phase in achieving measurable outcomesand enlisting the necessary financial and institutional support for future investments.As in other examples of regional Bank/GEF initiatives, these initial investments will serve to attract new resources by a range of partners, helping to institutionalize collaboration and sustain the Project through successive phases. It is anticipated that partnerships will expand and additional financing from research institutions, governments and private foundations will become the major source of funding in the subsequent phases of the program.

1a. Replicability:

Because the TR Project is structured around discrete research themes and networks of scientists it presents infinite opportunities for replication and scale up. In this initial phase, the Project investigations will be centered around four nodes and Centers of Excellence. Consistent with the availability of resources, the research design calls for the 6 Working Groups to focus their investigations at these sites to lend power to their research through integration of information across themes, in a case-study or demonstration project approach. The research agendas of each of the Working Groups, however, provide broad scope for replication at satellite sites in the region, expanding collaboration with other scientists and institutions around the node. Similarly, the opportunity exists to expand to new nodes and Centers of Excellence in subsequent phases, as demand and resources dictate. Successful implementation in Phase 1 will set the stage for scale up and replication in subsequent phases. The focus in subsequent phases or regions may shift away from filling basic knowledge gaps to strengthening capacity in coral reef countries and tools and interventions for better decion-making. Modeling and decision-support are among the tools that may be refined as knowledge gaps are filled and effort shifts to the application of knowledge to management. By the end of this five year phase, the Project will have documented a model for Targeted Research with wide transferability to other GEF Focal Areas.

2. Critical Risks (reflecting the failure of critical assumptions found in the fourth column of Annex 1):

Note "With respect to project objectives, there are no significant risks of failure of critical assumptions".

Risk	Risk Rating	Risk Mitigation Measure
From Outputs to Objective		(no significant risks)
From Components to Outputs Project Components 1-3. Continued support for the project by researchers in developing and developed country institutions is not sustained due to lack of political will or other priorities.	M	Centers of Excellence and associated academic institutions within host countries will need to be well integrated into the project, the benefits of their participation clear and tangible, and the importance of their work recognized by management.
Overall Risk Rating		

Risk Rating - H (High Risk), S (Substantial Risk), M (Modest Risk), N(Negligible or Low Risk)

3. Possible Controversial Aspects:

G. Main Conditions

1. Effectiveness Condition

2. Other [classify according to covenant types used in the Legal Agreements.]

H. Readiness for Implementation

☐ 1. a) The engineering design documents for the first year's activities are complete and ready for the start of project implementation.
☐ 1. b) Not applicable.

☐ 2. The procurement documents for the first year's activities are complete and ready for the start of project implementation.
☐ 3. The Project Implementation Plan has been appraised and found to be realistic and of satisfactory quality.
☐ 4. The following items are lacking and are discussed under loan conditions (Section G):

I. Compliance with Bank Policies

☐ 1. This project complies with all applicable Bank policies.
☐ 2. The following exceptions to Bank policies are recommended for approval. The project complies with all other applicable Bank policies.

Marea Eleni Hatziolos	Kristalina Georgieva	Ian Johnson
Team Leader	**Sector Manager/Director**	**Country Manager/Director**

Annex 1: Project Design Summary

WORLD: Global Coral Reef Targeted Research and Capacity Building Project

Hierarchy of Objectives	Key Performance Indicators	Data Collection Strategy	Critical Assumptions
Sector-related CAS Goal: The strategic goal of this Program is to enhance the sustainability of coral reef ecosystems as global commons, whose goods and services support the livelihoods and security of millions of people.	**Sector Indicators:** 1. Conservation of coral reefs and the goods and services they provide are priorities for reef countries, as reflected in economic development plans and support from the international community. 2. The CASes, PRSPs and CEAs of countries with significant coral reefs include discussion of the status of reefs, andtheir contribution to livelihoods and environmental/ economic security in that country.	**Sector/ country reports:** 1. Global Status of Coral Reefs Report (produced every two years by GCRMN). 2. National economic development plans, regional plans, integrated coastal management plans, etc. 3. Commission on Sustainable Development Reports; progress reports on follow up to WSSD targets on coral reefs. 4. Scorecards/performance reports of ICRI members.	**(from Goal to Bank Mission)** Continued commitment by countries and donors to conserve and manage coral reef ecosystems for sustainable use.
GEF Operational Program: International Waters: OP 9, Multiple Focal Area: To build capacity for science-based management of transboundary marine ecosystems under threat from climate change and multiple human stressors, through targeted research and learning across regions.	**Outcome / Impact Indicators:** 1. Formerly fragmented coral reef research efforts are coordinated and targeted for the first time around key sustainability themes. A coalition of scientists and research institutions from developed and developing countries is built to support this effort. [Six international working groups established and conducting research on peer-reviewed research agenda at participating host institutions in Yr 1.] 2. Major partners from different sectors are aligned with this initiative, building momentum toward a critical mass of resources and sustained commitment	1. Number and management-relevance of publications and reports arising from national research agencies 2. Number of directly commissioned research projects undertaken by research agencies. 3. National reports, quantitatively improved, with higher standards of confidence presented to meetings of the International Coral Reef Initiative (ICRI) 4. Annual reports from research institutions and management agencies associated with the Network Integration of findings and analysis of management decisions and	1. Implementation of project on a global scale proves too complex to achieve objectives. 2. Sustained co-financing beyond first phase is not forthcoming.

	to the targeted research beyond the initial phase.. 3. As they emerge, research results are peer reviewed, synthesized and broadly disseminated to a wide array of stakeholders. [Results of research peer reviewed annually for quality control and product delivery, synthesized and released for different audiences.] 4. Results are linked to management such that coral reef managers are empowered with knowledge and tools to make better decisions [Diagnostic and remote sensing tools and results of hypothesis testing come on line by end of year 2. At least 1 contribution/WG to NGO "managers' toolkits" and 2 policy briefs disseminated by EOP] 5. Institutional and human capacity for science-based management of coral reef ecosystems is built in participating countries where coral reefs are found. [COEs fully engaged in hosting research and training by EOP; number of publications by staff in peer-reviewed journals more than doubles by EOP.] 6. Policies in these countries to protect coral reefs or mitigate impacts from key stressors are strengthened as a result of new information. [At least 1 example of policy adoption or reform in favor of coral reefs documented by EOP]. 7. Research findings are	interview/questionnaires with management staff.		

	mainstreamed into World Bank country dialogue and assistance strategies for countries with coral reefs. [At least one example of policy l dialogue between a World Bank Country Director and client on action to reduce/mitigate stress on coral reefs is documented by EOP]. 8. Coral reef management projects under early implementation or in preparation — many with GEF support —incorporate research findings and links to TR in project design. [At least 3 cases documented]. 9. The GEF uses results to guide future resource allocations to address cross cutting issues in Climate Change, International Waters and Biodiversity in the context of transboundary water resources mgt, and to guide clients in the design of large-scale targeted research.		
Global Objective: 1. Addressing knowledge and technology gaps: --Uncovering critical unknowns that contribute to improved management. –Developing new tools and techniques for assessing coral reef stress, and for rehabilitating damaged reefs.	**Outcome / Impact Indicators:** 1. Working groups undertaking field work; new tools, information products and procedures for measuring and predicting coral stress and mortality developed and published by mid-term. Research results on causes, mechanisms, risks of coral stress and its	**Project reports:** 1. Project reports 2. Publications 3. Website content and visitation frequency 4. Formal feedback from workshops 5. Feedback from project participants (e.g., recorded on website forum area)	**(from Objective to Goal)** Coral reefs continue to provide a major source of protein and income to millions of poor people living in the tropical coastal areas, and thus management of coral reef resources continues to be a high priority in developing countries with significant

-- Publication of research results and conclusions of each working group. 2. Linking scientific knowledge to management: -Enhanced communication mechanisms between researchers and managers. --Management relevant information, advice and policy options in the form of periodic briefs issued by Steering Committee; --User friendly models of ecological impacts and decision-support tools indicating the cost/benefits of various management interventions. 3. Promoting learning and capacity building: Scientists and students with enhanced capacity to engage in targeted research. Institutions with increased capacity to engage in targeted research	ecological implications published in a variety of formats (in print and electronic formats) throughout Project. 2. a. Workshops with managers during strategic periods of the project; publication of management information briefs and policy option papers; creation of a continuously updated knowledgebase and information system for managers during the first year. 2. b. Availability of user friendly models for use by participating researchers and managers. Models being used collaboratively by researchers and managers on actual management issues by EOP.. 3. Inclusion of post-graduate students from host countries in the research activities of all working groups; active participation of senior research staff in research activities; improved research and technical capabilities of local institutions; exchanges of academic staff and students between local institutions and developed country institutions.		coral reef resources.
Output from each Component:	**Output Indicators:**	**Project reports:**	**(from Outputs to Objective)**

Project Components / Sub-components:	**Inputs: (budget for each component)**	**Project reports:**	**(from Components to Outputs)**
1. Addressing knowledge and technology gaps.	1. $14.0M	Progress reports and disbursement/ expenditure reports.	Continued support for the project by partners and by researchers in developing and developed country institutions.
2. Linking scientific knowledge to management.	2. $6.0M	Project Reports on no. of graduate and postdoctoral students trained between WG institutions and COEs; and WG institutional reports.	
3. Promoting scientific learning and capacity building.	3. $4.1M	Project Reports and number of policy briefs produced, participating NGO annual reports; refereed publications credited to the TR.	
Project Administration	4. $3.5M		

Annex 2: Detailed Project Description

WORLD: Global Coral Reef Targeted Research and Capacity Building Project

I. Key Knowledge Gaps (US$ 14.0 M; Cash Co-finance: US$ 8.5 M)

Coral reefs play a key role for the functioning of tropical coastal ecosystems and for the large coastal populations that depend on reef resources for their daily livelihoods. Complex and productive, coral reefs include an overall biodiversity that is critical for the ecosystem's natural ability to respond to environmental change. Coral reefs also provide critical resources (e.g. fish, tourism, coastal protection, etc) for at least 100 million people that depended either totally or partially on reefs (Wilkinson, 2002). Coral reefs are under pressure from a wide array of human influences. Recent evidence also reveals that coral reefs are very sensitive to environmental changes like climate change (Hoegh-Guldberg 1999; IPCC 2001). As a result of these pressures, coral reefs are in decline in almost every region of the world. Recent estimates put the rate of decline at somewhere between 40 and 60% of the world's coral reefs over the next 50 years unless appropriate steps are taken (GCRMN 2000). This has huge ramifications for a large number of human societies and endeavours as well as the inherent aesthetics of our coastal ecosystems.

Understanding how these changes will manifest themselves and how the impact on human and reef communities can be eliminated or minimized is an urgent priority. Despite significant progress over the last two decades, there are many key gaps in our basic understanding of coral reef function and dynamics which impede effective management of coral reefs in the face of climate change and direct human impacts. Each of the 6 working groups has met on several occasions over the last 12 months to identify the most critical gaps and how they may be filled through targeted, hypothesis-testing research activities. In the following sections a summary of the basic problems, and a detailed description of each research question is presented together with a description of the research approach and location of activities (see Supplemental Document 1 for more details on the activities for each group).

A. Bleaching Working Group (US$ 3.6 M; Cash Co-finance: US$ 2.1 M)

1. Susceptibility and Tolerance of Corals to Rising Sea Temperatures

This project aims to provide management with the scientific knowledge and capacity to respond to the impacts and outcomes of increasing global climate change on coral reefs. There are 3 major activities: 1) A description of the molecular mechanisms (sub-cellular processes) associated with the breakdown in photosynthesis within the symbiotic algae in corals during thermal stress; 2) A characterization of differences in these processes between tolerant and susceptible corals; and 3) A exploration of the relationship between the genetic makeup of the of corals and their tolerance to bleaching and thermal stress.

These activities will fill important gaps in our understanding why there is so much variability in the degree of bleaching between different corals both in the same location and at different locations. They will also provide important clues to the exact physiological cause of bleaching, and insights into the potential for corals to become acclimated (or perhaps sensitized) to heat stress under different circumstances.

The first activity will test, using standard photo-physiology methods, if the photosynthesis apparatus is the first point of failure during thermal stress, or it the first damage is to photosynthesis in Photo-System II. It will also investigate the different susceptibility of different zooxanthellae species and the role of other factors such and increased visible and UV light on the breakdown of photosynthesis during thermal stress.

The work will be carried out at the Puerto Morelos lab in Mexico and at Heron Island.

The second activity will use the fact that many animal cells immediately respond to thermal stress with activities aimed at re- adjusting the cellular environment to maintain normal metabolic functions (homeostasis). These responses may include, but are not limited to, increased production of heat shock proteins, activation of oxidative stress pathways and osmoregulation. Persistance of the thermal stress overwhelms these homeostatic activities and elicits the "stress response" which may cause the loss of symbionts through multiple pathways (e.g. exocytosis, apoptosis, necrosis). The presence and pattern of occurrence of these chemical stress signals will fill an important gap in understanding the role of the coral's physiology in adapting to thermal stress and may provide an early indicator of impending bleaching and mortality, or of otherwise undetectable episodes of near fatal stress. The work will be carried out it Puerto Morelos and Heron Island.

The third activity will map the diversity of zooxanthellae and correlate genetic differences to physiology and tolerance to thermal stress. This is a fundamental knowledge gap which will enable the other activities on thermal susceptibility and resilience to be examined in relation to the specific strain or species of algae. The work will use standard molecular genetics techniques already developed by the participating researchers. It will be carried out at all research sites as well as additional locations to ensure a global coverage of samples.

2. Impact of Global Climate Change on Coral Reefs Ecosystems

This project will address the important question of what effects the sub-lethal stress and mortality of corals will have on the structure and function of coral reef ecosystems. The exact cause of this stress and mortality is addressed in the previous project. At the lowest level it will investigate a variety of responses of individual coral colonies and coral populations (including growth, reproduction, recruitment, energy reserves, monopolization of reef substrate) during bleaching and non-bleaching periods. The environmental factors that influence the response and recovery of corals to thermal stress and climate change will determine the resilience and adaptatation of coral reefs. The main components at the population to community level include 1) the main physical factors (water flow, light, nutrients, competition with other groups such as algae, herbivory and predation), 2) the susceptibility and 3) recovery of the various taxa. These factors will be studied in study sites with a variety of taxa and environmental factors. Sites will be chosen to be representative of the full range of likely ranges in these factors in each region. Sampling will be structured heirarchically, building on long term broad scale monitoring (transects, video, etc) using permanent quadrats/belt transects for tracking coral population variation and linkages to organismal variation.

This will be put into a long-term historical perspective through a review of the paleo-environmental history of each site to determine if, through the geological record, coral communities and their environment have been relatively stable compared with recent times.

Based on the results of the activities above, and previous published research, a series of models will be developed for predicting the responses of different coral species to stress such as heat and light. This will provide critical insight into how changes to stress might affect primary production, growth and reproduction. This study will incorporate an assessment of the interrelationships among population and community response variables and thermal stress gradients. It will also examine the relationship between population and physiological response variables.

Understanding the link between microbial community changes and coral health is critical if we are to

understand how reefs may change under human enhanced climate change. This activity will assay the microrganisms living in association with healthy and bleaching and will investigate the links between colony health and disease resistance and the functional changes in microbial communities associated with dead and stressed coral surfaces.

Coral mortality and thermal stress are expected to influence biodiversity of multiple taxa This study will examine past and present levels of biodiversity in reefs with various histories of bleaching and coral mortality. It will be based on a review of existing literature, a synthesis of data that these investigators have collected and also by resurveying sites in each regions where good data are available and can be repeated and compared to examine changes over time in relationship to thermal stress.

Coral reefs have been shown to respond in a variable manner to alteration in nutrient loads and changes in community structure after coral mortality or removal. There is a current understanding that any significant change at the level of regional bleaching events, or wide-scale anthropogenic inputs, may result in a fundamental shift in the community structure and subsequent trophodynamics of the reef. This activity will determine if reduced living coral cover suffer from reduced calcification and increased erosion, and if they have different nutrient dynamics. It will also determine if bleaching will lead to major changes in the carrying capacity of coral reefs for other anthropogenic disturbances.

3. Tools to Identify and Monitor Stress

This project will rapidly expand our knowledge and our capability to characterize, explore and monitor stress on host and symbiont (Symbiodinium spp.) in Scleractinian corals. The major aim of this project is to exploit new genomic technologies to rapidly obtain a better understanding of interface between reef-building corals, Symbiodinium spp. and the environment. The following activities will be conducted in sequence: a) Establish a library of 5,000 Expressed Sequence Tags (ESTs) from a single strain Symbiodinium spp. (clade C1) and 5,000 ESTs from its coral host from the common coral-dinoflagellate symbiosis From this, a Symbiodinium DNA Microarray (SDM) using the EST sequences will be produced; b) Produce an Acropora DNA Microarray (ADM) using the EST sequences; c) Identify key genes within the coral host. Laboratory trials (where applicable) will help define the properties, behaviour and range of conditions under which selected bio-indicators are developed. Extensive field testing of bio-indicators will be conducted for all potential bio-indicators.

In identifying which corals are most sensitive ecologically, procedures will be developed that will enable "ecological markers" of disturbance to be used. These include the use of standard colour cards to document the degree of coral bleaching in a standard, unbiased manner so that comparisons between sites, times and observers are meaningful. These will be field trialed at the four supersite locations using a range of species.

4. Socio-economic consequences of Climate Change Impacts on Reefs

Using data generated by this project, the projections of how coral reefs will fair under climate change generated by previous models will be extended and developed. Using the latest climate models and the principal IPCC scenario projections, models will be built to estimate how coral abundance, reef biodiversity and health will be projected. In addition, a review, assessment and scenario building exercise will be conducted to examine the impacts on fisheries and tourism under future climate change scenarios.

5. Management implications/outcomes

The suite of activities to be undertaken by this working group will provide managers with a deeper understanding of the mechanisms which cause bleaching in corals, and the consequences of these changes to broader coral reef ecosystem. This will allow managers to develop ameliorative regimes which minimize both the causative factors as well as other exacerbating conditions which may be more readily controlled within managed areas. It will also allow managers to identify areas of higher risk, as well as those which are likely to exhibit long-term resistance. This knowledge will be crucial in the development of effective networks of protected areas aimed at maintaining biodiversity and sustaining productivity. A better understanding of the full range of variation in susceptibility and resilience, and its source (host or symbiont) will provide managers with insights into which corals, or species of algal symbiont are likely to be most resistant. This knowledge would enable managers to promote the recovery of areas devastated by bleaching through the selection of more resistant strains or species.

The elimination of exacerbating factors may prove to be the most important practical tool available to managers in the during periods leading up to and during bleaching. The development of biomarkers and stress indicators by this working groups will enable managers to quickly identify areas needing management intervention to reduce additional stress from human activities.

6. Linkages with other WGs

There will be strong links between this group and the Remote Sensing, Diseases, and Decision Support groups. In particular, the remote sensing group will provide thermal anomaly data (hot spot and degree heating week products) which will be used to generate models of predicted bleaching, and identify likely bleaching areas for ecological studies. The Diseases working group will be involved in the activities on the relationship between the microbial communities on healthy and bleached corals. Joint activities will address the hypothesis that coral bleaching is, at least in some cases, a microbial disease. Finally the modeling and Decision Support working group will be consulted in the development of global bleaching models.

B. Disease Working Group (US$ 2.02 M; Cash Co-finance: US$ 0.5 M)

Coral disease impacts have increased on reefs worldwide, but perhaps especially in the Caribbean, where disease outbreaks have played a significant role in the loss of key reef organisms and coral cover (Figure 1; Weil 2002). Today, disease of coral reef organisms stands out as a key factor in the deterioration of Caribbean coral reefs. While there are relatively few reports from the Indo-Pacific and the Red Sea, our initial surveys for the this GEF project do show, for the first time, significant and rising levels of coral disease in Australia and Philippines. The emergence and prevalence of diseases/syndromes in the Caribbean in the past few decades appears to be unparalleled in the geological record. Limited paleontological evidence suggests that a recent outbreak of white band disease, which killed acroporid corals in Belize, was unprecedented on a time-scale of at least three millennia. One hypothesis is that rising disease occurrence is related to increasing anthropogenic impacts (Kim and Harvell 2002; Kuta and Richardson 2002). For example the current warming trend of the oceans, the increasing frequency of African dust storms due to desertification of the northern Sahara, and continuing sediment/organic inputs due to deforestation around the globe. However the links are not always clear, and require further research.

One of the most difficult challenges facing coral disease researchers is determining if a report of a disease/syndrome in a new reef region represents a previously reported disease/syndrome from another reef region. The pathogens for the majority of these syndromes have not been identified. Therefore most diseases/syndromes have been named according to their ecological (rather than pathological) characteristics, creating confusion in the number of diseases/syndromes present. Current research on disease reservoirs and vectors is hampered by lack of knowledge of the pathogens causing the majority of

coral diseases. To date, disease reservoirs have only been identified for black band disease and aspergillosis, and only one disease vector for one disease has been identified. In addition, little information is available about whether bleaching and disease outbreaks are related. Similarly, our knowledge of coral resistance to disease is effectively a black box, despite the potential importance of coral resistance in eventual remediation efforts.

During preparatory discussions the Diseases working group prioritized the research avenues that will provide the most direct outcomes to managing reefs under disease threat and also lead to the most productive opportunities for global capacity building in coral epidemiology, disease ecology and management. These priorities are: 1) a global assessment of coral diseases, 2) advancing understanding of epidemiology (origins, vectors and spread rates) of coral diseases, 3) evaluate major mechanisms of coral disease resistance, 4) pinpoint the ongoing impacts of coral disease on coral biodiversity, coral community diversity and population growth.

1. Role of environmental factors in causing disease

Before we can fully explain the causes of disease, we must better understand its geographic distribution and prevalence. One explanation for the relatively sudden emergence of coral diseases/syndromes is changing and deteriorating environmental conditions. Changes in climate, such as the current warming trend of the world's oceans, could make pathogens more virulent and/or hosts more susceptible to disease. Thus a first priority is a global disease assessment, stratified over temperature and nutrients gradients.

Specific questions to be addressed are:

- Is the prevalence of coral disease correlated globally with warming trends (measured as Degree Heating Weeks, DHW)?
- Is coral disease prevalence correlated with regional ocean warming and water quality?
- Is disease prevalence correlated with local point sources (silt, nutrients)?

These questions will be addressed through a global census at 24-36 sites on an annual basis. All signs of disease will be recorded on replicated transects, and samples taken for identification of pathogens. Local scientists will be trained to carry out follow-up rapid surveys. Tissue samples from algae and soft corals will be used to determine local nutrient loads. Surveys and samples will also be taken sites adjacent to and away from point sources of pollution. This work will be carried out in the Philippines, Palau, Hawaii, Australia and the Caribbean.

2. Pathogens – origins, reservoirs and modes of transmission

In order to address the major gaps in our understanding of the organisms causing most diseases, where they are nornally prevalent, and the mechanisms by which they are transmitted to new hosts in new areas, the following questions will be addressed:

- Is coral disease caused by a variety of microorganisms of which many are opportunistic pathogens?
- Are common coral predators acting as vectors and or reservoirs of coral disease?
- Are reef sediments major reservoirs of coral pathogens?
- Do pathogens for some coral diseases originate from land?

Samples will be taken form diseased and healthy tissue and analysed for differences in the microbial

community. A variety of molecular tools to identify previously unknown pathogens will be employed. Once pathogens have been identified, a suite of techniques that could facilitate rapid assessment of disease in corals will be developed, including genetic probes. These could also serve in verifying the presence of pathogens and be utilized to trace the route of pathogen transmission, such as through identification of vectors and reservoirs of the infectious agent.

Specimens of most coral predators will be collected from different reef sites and screend from the presence of specific pathogens. Similarly, sediment and algal mat samples will be collected, stored, and shipped to the lab for microbiological analyses. To identify the origin of *Aspergillis sydowii* (which is also found African dust) in the marine environment, variable microsatellite markers will be developed. Five to seven variable microsatellite markers for *A. sydowii*, will be compared with pathogen strains isolated from diseased Caribbean gorgonians, African dust, terrestrial sediments, and oceanic samples. We plan on using a similar approach to investigating origins of other coral diseases, especially those with potentially traceable origins.

3. Coral resistance to disease

This group of activities will determine what the effects of climate and environmental factors on the surface muco-polysaccharide layers (SML) of coral and the bacterial communities which live on them. It will also investigate the effects of climate and environmental stress on coral immunity to diseases.

Specific questions to be addressed are:

- Can environmental factors alter the surface microbial community?
- Are shifts in mucous microbial community correlated with disease outbreaks?
- Do corals have a range of inducible physiological responses to infection?
- Do climate and anthropogenic stress compromise coral immunity and facilitate disease outbreaks?

Coral samples from both coral mucous and sediments will be collected from transects in different environments. Changes in the mucous community over time will tracked in both healthy corals and those developing disease symptoms. To investigate immunity, gorgonian sea fans will be studied to determine if a range of inducible anti-microbial chemicals are produced, and if these are produced in the animal or the symbiotic zooxanthellae. Finally, once specific mechanisms of resistance have been identified, they will be incorporated into a coral resistance chip or micro-array, which allows several thousand possible resistance factors to be analysed at once. Field sampling will enable estimation of the magnitude of genetic variation in sea fan resistance, quantification of the response of fans to different experimental treatments of enhanced nutrients and temperature, and mapping of spatial variation in sea fan resistance in the field.

4. Impact of disease on coral reef ecosystems

This topic will examine how disease changes reproduction and population dynamics of corals, and how disease changes coral biodiversity and the community structure of coral reefs. Diseases have the potential to alter rates of fundamental demographic processes like recruitment and mortality, and dramatically change the structure of coral populations, but almost no data exist to demonstrate this. These potential impacts could significantly impede the potential for recovery of coral populations following disease outbreaks, further compromising their resilience. Disease, particularly when species-specific, has the potential to reduce coral biodiversity on local and even regional scales, but we have only a preliminary understanding of global patterns in the impact of disease on coral biodiversity. The types of community phase-shifts ultimately inducible by coral disease and the role of biodiversity in ameliorating the impact of

disease on community structure are also poorly understood. When framework-building coral species are targeted by pathogens, disease outbreaks may change reef community structure fundamentally. Given the diversity of coral pathogens and the wide range of susceptible coral species, increase in disease incidence, for example in response to global warming, is likely to induce phase shifts in coral community structure. Disease-induced mortality of abundant and / or major framework building corals will also have catastrophic implications for topographic complexity of reefs and the availability of habitat or shelter for the majority of reef-associated organisms. Equally worrying is the potential impact of disease on the resilience of coral assemblages.

Specific questions to be addressed in relation to the above issues are:

- Is disease changing the reproductive output of coral populations?
- Is disease is changing the population dynamics of key coral species?
- Does high biodiversity limit the impact of disease on coral communities?
- Can coral diseases induce shifts in scleractinian community structure?

Samples of healthy and diseased colonies of three coral species in each region will be collected prior to spawning, and their reproductive output measured. A long-term monitoring program will be set up at three sites on each reef in the Caribbean, Great Barrier Reef and the Philippines. Permanent transects will be video taped and analysed for the incidence of disease. Using tagged colonies demographic data on growth rates, rates of partial and whole colony mortality, and rates of sexual and asexual recruitment will be collected. Based on these data, the incidence of disease and rates of transmission and mortality and their impact on population growth will be modeled and compared between reef regions. Changes in coral biodiversity through time will be documented to determine whether functional redundancy associated with high biodiversity reduces the susceptibility of coral reef communities to phase shifts towards degraded structures. Changes in the percent cover of benthic categories over the 5 years of the program will highlight whether disease has caused changes in community structure over the timeframe of the project and whether such changes have led or are likely to lead to phase shifts in the dominant components of reef communities.

5. Management implications/outcomes

Knowledge of how responsive disease is to warming episodes will be an invaluable tool for tracking the progress of disease, as well as identifying disease "hot spots" upon which we will focus further attention. This will give developing countries, particularly in the Indo-Pacific, information about the health status of their reefs and methods for continued monitoring. The assessment of disease facilitators such as nutrients and temperature will give provide information and tools to direct management issues such as siting of MPAs, increasing standards of water quality and controlling pathogen inputs.

Arguably the most critical information for managers of diseased populations is the origin, routes and spread rate of a new pathogen. The results of the group's work will help to guide reef management decisions, such as where and when to site MPAs, how directly should they be linked, what habitats should they include. The capability to predict disease outbreaks 6-12 months in advance through an understanding of the effects of environmental factors on disease development will be a powerful management tool. Understanding the longer-term potential impacts of disease on coral populations and communities is critical for the development of appropriate management responses. For example, controlling inputs through reducing point source pollution may only be economically viable if a disease has a wide host range and will clearly reduce coral biodiversity and cover.

6. Linkages with other Working Groups

Strong linkages exist between this group and the diseases working group, which will be investigating possible links between bleaching and disease. PAM fluorometry in collaboration with the Bleaching group will be useful for field-based assessment of coral health and thermal physiology. The results of the modeling and connectivity groups will also be used in predicting the possible spatial pathways of disease propagation, which is likely to be similar to the dispersal of fish and invertebrate larvae. Similarly the outputs from the remote sensing group will be useful in detecting potential hotspots of thermal stress and disease outbreak. Linkages with the modeling group will be important for maximizing the predictive power of population dynamic models developed to predict the impact of disease on coral populations.

C. Connectivity Working Group (US$ 3.1 M; Cash Co-finance: US$ 1.6 M)

Coral reefs are patchily distributed in an ocean that provides the possibility of transport among them. Connectivity is the flux of items between locations. It exists for nutrients, sediments, pollutants, and individual dispersing organisms – any item that has the potential to move among reefs, or between reefs and other types of ecosystem including island and continental margins and their watersheds. In the context of coral reef management, the effective transfer of individuals (usually pelagic larvae) between local populations is one of the most important, and certainly the most difficult form of connectivity to quantify. At present we lack quantitative data on demographic connectivity for any reef species.

At present we lack quantitative data on demographic connectivity for any reef species, although there is wide recognition that pelagic larvae must disperse to some extent, and considerable information on the larval durations, timing and location of spawning, and larval biology of many species. Increasingly, the management of coastal marine systems is spatially explicit, utilizing some form of marine protected area (MPA) or no-take zone as a way of regulating human impacts on local populations of organisms. Often the management necessarily crosses national boundaries in coastal seas. The research activities for this group are divided into two major themes: 1) Dispersal of larvae from spawning sites will be studied using: a) experiments to track or model movement of larvae from their source location where spawning occurs, to the site of settlement; and b) experiments that use the pulsed mass spawning events, which flood the environment with larvae from a particular species at a specific time, to identify the likely source of new recruits at potential settlement sites. These experiments will rely on the (testable) hypothesis that recruits have specific chemical attributes which can be related to their site of origin. 2) The recruitment of new individuals to local populations on coral reefs will investigate what factors influence survival immediately after larvae arrive at their final destination, and what role local factors play compared with factors influencing larval condition during the dispersal phase.

The research for this group will be carried out, during the initial years in the Mesoamerican Barrier Reef system. In subsequent years additional work will be carried out in the Philippines and Palau, and possibly other core sites in Africa.

1. Dispersal from spawning sites

a. Flux experiments

The dispersal paths of larvae from their natal reef will be studied by addressing following specific questions:

- Can studies of coral larval behavior and competency periods be used together with hydrodynamic modeling to predict dispersal?

- Can genetic and demographic approaches be used to identify patterns of connectivity in coral populations?
- Are larval or post larval biology or behavior important in modeling pelagic dispersal of lobster?
- How important is larval connectivity to lobster recruitment and sustainability in Mesoamerica?

b. Pulse experiments

The ability to infer dispersal patterns from mass spawning species will be addressed through the following research questions:

- Can connectivity be measured for groupers or snappers using traditional spawning aggregation sites?
- Can natural variation in otolith chemistry or genetics be used to estimate connectivity in a region?
- Can mass spawnings be used to follow and model dispersal of coral propagules from a source population?

The exact sequence of some experiments and questions to be addressed will depend on the outcome of initial work aimed a testing assumptions and confirming the ability to identify the natal source reef of based on environmental markers in the otoliths of larvae, DNA fingerprinting, and on other chemical markers in fish and invertebrates at both adult and larval stages. Direct tagging of larvae with specific chemical markers will also be trialed (based on previous successful pilot studies).

The source distribution of adult spawning stocks will be determined using physical tags. Much of the work will depend on the application and refinement of existing hydro-dynamic models of currents and particle dispersal trajectories for the region. During coral spawning periods, direct tracking of buoyant larvae together with the use of neutrally buoyant beads which can be instrumentally detected will allow the dispersal trajectory of larve to be studied, and compared to model predictions.

2. Relationship of dispersal to recruitment

This area will be investigated through the follow specific research questions:

- Can spatial and temporal patterns in recruitment aid estimates of connectivity in fishes?
- Do local and regional differences in reef 'condition' that affect settlement & post-settlement survivorship override patterns of dispersal potential and limit connectivity?
- Can biophysical models be developed that will adequately predict patterns of settlement of postlarvae?

This work will involve on comprehensive surveys of new recruits (<1 month old) at a variety of sites and a comparison of the spatial pattern of recruit variation with inferred natal source as well as the local environmental attributes of the each recruitment site. A comparison of the observed recruitment patterns with those predicted from dispersal models incorporating both passive and active larvae movements will then be conducted.

Studies on larval behavour and competency, small scale spatial settlement patterns and survivorship of corals, and regional recruitment patterns and regional surveys of coral populations size structure will be used to derive predictive models of recruitment which can be compared with hydrodynamic models.

This work will be carried out primarily in the Mesoamerican region. Research in the Philippines and Palau

will begin by years 4 to 5.

3. Management implications/outcomes

Two major outcomes expected:

- empirical data will lead to much better management of populations and MPA design
- development of new technologies for tracking dispersal (genetics, trace element chemistry of otoliths)

Decisions guiding the implementation of spatially explicit management actions, such as the establishment of MPAs, are currently made without any quantitative data on connectivity of target species, although the fundamental importance of such data is broadly recognized. The consequences of the research of this group for management decision-support are substantial. There will be an explicit description of connectivity for one or more target species at a particular location that could be used immediately in management decisions there. The particular results help sharpen the 'best guesses' being used in making management decisions on other species and in other locations. The methods tested and developed during the project will be important management tools which will yield results that can guide management decisions on other species and in other locations in future. Over time, conversations among managers are much more likely to establish that connectivity data are essential than will conversations among academic scientists. A major goal of the program must be to articulate the need, develop the tools and ensure the tools are in the managers' hands. The placement of sampling and experimental sites will be done in consultation with management agency personnel to maximize the possible benefits of the work for current management activities. Workshops planned in region will directly engage management agency and NGO personnel. Efforts also will be made to build links to other large projects in place in each region.

4. Linkages with other WGs

Most of the outputs of this working group will be incorporated into the models of the Modeling and Decision Support Group. In addition the dispersal and connectivity patterns elucidated by the group will be used to the Diseases group to predict the transmission and spread of coral disease in different areas. The image products of the Remote sensing working group will be used by the Connectivity group to identify possible spawning aggregations sample sites, to identify appropriate habitats for recruitment and adult populations surveys, and to ground truth the detailed hydrodynamic models of Glovers reef in the Mesoamerican Reef system. Coral recruitment data will be shared the Remediation Group as well as the Bleaching and Diseases Groups. Field work to collect coral spawn could be combined with these groups. Development of genetic markers could be done in conjunction with similar work by disease and bleaching groups, so that tissue samples could be shared and field logistics combined. Collections of fish for genetic analysis will be carried out by other groups during their field work in order to obtain larger samples from more sites. Finally sites for recruitment studies will be shared with remediation and other groups (bleaching, diseases) wherever possible.

D. Restoration Working Group (US$ 3.3 M; Cash Co-finance: US$ 1.8 M)

Recently there has been an explosion of mitigation projects and global efforts towards habitat restoration. The diversity and scale of remediation/restoration activities vary tremendously, and these will continue to have an increasingly important. 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. Levels of understanding are still largely based on personal experiences.

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.

Rehabilitation measures have not always successfully compensated for the fast degradation of many reefs. The applicability of techniques such as in-situ coral mariculture for example, on large-scale reef areas needs further evaluation. However, there is little sense in restoring a reef degraded by anthropogenic activities unless those activities have ceased or are effectively managed and the cause(s) of degradation removed. In addition, it is essential that the long-term efficacy and cost-effectiveness of restoration be evaluated under differenc circumstances. Interventions must always be compred to the non-intervantion case. In other words, what would happen if natural recovery process alone were allowed to operate over a 5-10 year timescale?

The research areas identified for this Working Group during Block B consultations are divided into 3 main areas: 1) Measurements of normal rates of recovery without intervention; 2) The incremental effects of enhancing key biological processes such as sexual reproduction/ recruitment, asexual reproduction/transplantation and provision of suitable settlement surface through increased grazing; and 3) The incremental effects of providing modified (or artificially enhanced availability of) substrate for coral settlement.

1. Normal rates of reef recovery

This activity will make use of standardized modules (Reef Balls) of two different sizes, in arrays of 5, with 5 replicates. All modules will be regularly monitored for coral cover growth, mortality, species number, recruitment. In addition adjacent 5m x 5m plots of healthy coral reef areas will also be monitored as additional natural controls.

2. Direct enhancement of biological processes

The effects of added larval abundance will be measured by collecting coral larvae from naturally occurring slicks, and concentrating them around replicated Reef Balls. These will be monitored for recruitment rates and subsequent growth and survival compared with control balls and recruitment plates in natural control areas. A land-based coral larvae hatchery will be established near the primary site. During the coral spawning period, gametes will be collected from individual colonies and reared to settlement stage, and then induced to settle on chemically coated material and kept in the hatchery. The growth, and survivorship of recruits kept for different periods of time before being place on experimental Balls will be measured.

The possibility that increased algal grazing by the common Trochus snail will enhance the growth and survival of transplants will be tested through the addition of trochus to some of the experimental balls. All treatments will be analysed by comparison to the control balls and natural areas.

Transplantation experiments will involve a determination of the minimum size, and the most appropriate coral species and growth form which will maximize growth and survival of fragments transplanted to replicate Reef Balls. At the same time monitoring the growth and survival of donor colonies used for transplants will provide information on which species are most tolerant of harvesting. The utility of coral nubbins (very small fragments) in restoration will also be measured using large numbers of nubbins of different species at all sites. The importance of the initial size and shape of the transplants will also be investigated. The possibility that coral recruits, nubbins and branch fragments will grow and survive better if they are first allowed to grow in dedicated land-based (ex-situ) nursery under controlled conditions before

being transferred to in-situ nurseries for establishment prior to transplantation, will be investigated at all sites and regions, including the Red Sea.

The effects of different species mixes and transplant densities will be investigated in 3m x 3m plots in the Philippines.

3. Substrate modification

Most of the Reef Balls will be constructed from normal concrete cement. However the possibility that the substrate composition affects the performance of recruits and transplants will be tested using a set of experimental balls constructed with limestone rock aggregate. These will then be monitored in the same way and at the same time as the experiments testing larval enhancement, and addition of corals of varying sizes.

4. Management implications/outcomes

One of the first products of the Working Group will be a Managers Guide which review the various existing restoration methods and describes under which circumstances they may be most appropriate. This will then be revised near the end of the project in the light of the experimental results. Through these products and other reports, workshops and briefings, managers will gain valuable insights into when restoration is appropriate, and which techniques would best apply to specific cases under their management. Careful recording of time, personnel and monetary investments for each experiment will provide important guidelines regarding the cost-effectiveness of otherwise equally efficacious methods.

5. Linkages with other WGs

Information on recruitment, spawning patterns and post recruitment survival will be shared with the Connectivity Working group as well as the Modeling and Decision Support Group. Imagery form the Remote Sensing group will be used to select the experimental sites, and areas for nurseries. Any data on diseases recorded during monitoring of transplants and recruits will be shared with the Diseases Working Group.

E. Remote Sensing Working Group (US$ 2.0 M; Cash Co-finance: US$ 0.5 M; NOAA in-kind Co-financing: US$ 10.0 M)

To manage coral reefs sustainably, practitioners and scientists require a vast array of spatially-explicit information. Spatial data are, for example, needed to design effective networks of Marine Protected Areas, monitor the health of coral reefs and provide an early warning system of major sources of stress. However, reefs are complex systems, affected by multiple natural and anthropogenic processes which operate across many scales. Remote sensing provides the only practical means to measure such processes and quantify their effects on coral reefs at meaningful, and often large, spatial scales.

The Remote Sensing Working Group (RSWG) will develop a multi-scale physical and biological observing system for coral reefs. Our aim is to improve the efficacy of coral reef management using three approaches:

- Provide better information for managers by developing and testing the tools necessary to measure and monitor the status of coral reef ecosystems at multiple ecological, spatial and temporal scales
- Improve the use of spatial information by developing the application of remote sensing products for conservation science and spatial decision-making

- Critically examine the cost-effectiveness of new methods to ensure that overselling does not occur

1. Monitoring of coral reef health

In the future, remote sensing has enormous potential for mapping the status of coral reef health. To date limitation in sensor resolution has limited that utility to rather coarse estimates of habitat and depth, and (in a few cases) benthic cover. However with the development of new sensors with high spectral an spatial resolution and new platforms (spaceborne, airborne and towed) the possibility of more detailed status monitoring needs to be carefully tested and described. This project develops promising new methods to distinguish the cover of reef taxa within high resolution imagery (pixel sizes of metres and many spectral bands). Outputs of the project will provide better information for spatial decision-making and measurably improve the cost-effectiveness of reef assessment and monitoring. A custom-built software package will be produced providing (i) training modules, (ii) automated and unique processing routines for reef imagery, (iii) a database of spectral signatures from many parts of the world and (iv) a tool which allows managers to plan a cost-effectives remote sensing campaign for a specific objective, location, water quality and budget.

The following specific questions will be examined:

- How do spectra mix in a coral reef system and what is the most appropriate unmixing strategy both with and without independent data on bathymetry?
- What is the linkage between optical spectra measured remotely and at the sea floor
- Can we measure coral and algal cover from a towed instrument array
- How do taxon-specific spectra vary geographically
- What is the importance and size of non-linear optical properties above different habitat types
- What is the efficacy of bathymetry predictions from optical satellite imagery
- What are the multi-sensor capabilities for mapping reef communities
- Can acoustic methods can distinguish coral communities
- Do reef communities differ significantly in their texture
- What aspects of coral reefs can be monitored indirectly using a time series of imagery?
- What are the optimum spatial and temporal scales for various environmental parameters from a user's perspective

These questions will be investigated using a combination of remote sensed data and ground truth information from standard reef surveys. The work will be carried out initially in the Mesoamerican Reef System and then in the Philippines and Palau.

2. Environmental monitoring (temp, solar radiation, turbidity,etc.)

A wide variety of oceanographic and atmospheric remote sensing products are available for reef management but many are in disparate locations and management unfriendly formats. Web-based Coral Reef Environmental Atlases (CREAte) will be created to collate and re-analyse a wide variety of existing data products (e.g. sea surface temperature anomalies, photosynthetically active radiation, water quality anomalies, wind speed and direction) and make them available to practitioners worldwide. New observational products will also be pioneered that are specifically focused on management issues such as mass coral bleaching events and deteriorating water quality. In addition the ability of CREWS data to be now-casted using existing satellite products (e.g. SST,wind etc) will be investigated.

3. Predicting resilience to thermal stress

This topic will address the question: Is the incidence of mass coral bleaching predictable in the near term and future? Physical models, based on hydrological and tidal information, show great potential for predicting how sea temperature will vary across a reef system given a certain amount of heating (i.e. which regions tend to heat up fastest and which remain cool). Such models will be developed and tested.

4. Mapping as management tool

This project will clarify the biological basis of individual habitats and the degree to which such habitats can be used as a surrogate for species in biodiversity planning. The species composition of reef habitats will be quantified in both Caribbean and Indo-Pacific regions. This project will draw on the expertise of scientists throughout the targeted research project and build the capacity in focal nodes to undertake detailed biodiversity studies. Acoustic remote sensing methods also provide insight into biodiversity questions. Acoustic data measure the structural complexity of the reef and since many fish species seek out shelter in complex habitats, the project will investigate the degree to which fish density can be predicted from remotely-sensed data.

The following specific questions will be addressed

- Do maps of geomorphological classes and community classes serve as a surrogate for species-level diversity
- Can acoustic remote sensing be used to predict patterns of fish density (i.e rugosity / density relationships)
- Can habitat and beta diversity be used for MPA planning

5. Management implications/outcomes

Recent developments in remote sensing will enhance the cost-effectiveness of coral reef management. Firstly, the cost of conducting many routine remote sensing tasks is falling because data are becoming less expensive and easier to manipulate. Secondly, and perhaps more importantly, the effectiveness of management will increase. Improved technology will allow several time-consuming management tasks, such as environmental monitoring, to be undertaken remotely, thereby freeing up staff and resources. Moreover, new technology provides fresh insight into coastal impacts and the vulnerability of coastal resources to such impacts. These insights enrich the knowledge-base for management, which, together with more detailed spatial information, will lead to better decision-making.

6. Linkages with other groups

There will be very strong linkages with most groups, especially the Bleaching Working Group who will use thermal imagery to predict areas of bleaching, and who will provide ground truth data from reef survey sites. Satellite colour imagery of all principle sites will provided to other groups to assist with planning field work and study site selection. Information from the remote CREWS weather stations will likewise be shared with all groups. All other groups will provide ground truth data from any surveys they conduct.

II. Scientific Learning and Capacity Building (US$ 6.0 M; Co-finance: US$ 3.0)

A. Developing country participation in WG research

Each of the Targeted Research Working Groups will be carrying out the majority of their field work in

developing countries. During the first years Mexico, and the Philippines will be the most active sites. Palau, and Belize will also be involve to a lesser extent at this time. In years 3-5 East Africa (Tanzania; Kenya) and Papua New Guinea will be brought into the projects in a progressive manner. Developing country participation will take several forms:

1. Participation by local scientist as full member of the Working Groups

The reader is referred to the technical annexes in Supplemental Document 1, for a list of each working group's members.

2. Participation of other local scientists as researchers/collaborators in specific experiments.

In addition to its formal members, each working group with have a network of affiliated scientists with whom they will collaborate on specific investigations at various sites, thereby accessing local knowledge and expertise, and ensuring long-term support for the research. Such collaboration will also help ensure the near-term application of findings to local/regional management issues.

3. Participation of university and government laboratories and field stations and their support staff as key research and experimental facilities for many working group activities.

The selection of study sites within the four research nodes is based on a case study approach, incorporating biogeographic considerations as well as the need to consolidate efforts around a minimum number of sites to maximize efficiencies in data collection and synergies between working groups. As the program develops, it is anticipated that the number of sites will increase, allowing for replication of experimental work and a wider geographic coverage of coral reef ecosystems and research institutions. In the first two years, 3 laboratories in developing countries will be used as bases for research activities. These are the University of Mexico Puerto Morelos Lab in Mexico, the University of the Philippines Marine Sciences Institute Research Field Station at Bolinao, Philippines, and the Palau International Coral Reef Center in Palau (tentative). Discussion are being held with scientist in WIOMSA and Tanzania to investigate the feasibility of using Research facilities and field stations in East Africa, and the possibility of using facilities in Papua New Guinea will be investigated in the first year.

4. Participation of local NGO's and coral reef managers in initial planning and awareness workshops during year 1; and in major workshops to disseminate results and conclusions, and to discuss their management and policy implications.

Based on preliminary discussions during the Block B phase, and further discussions during the early part of year 1 a number of active NGOs and management agencies will be invited to participate in workshops which will present the objectives and management relevance of the proposed research and seek input on site location, participation in some of the survey work, and plans for interpreting and disseminating the results of the research in terms relevant to managers and local NGO staff. This will be followed in year 4, with another series of workshops in each region to discuss the results and consider their incorporation into management plans and future policy, and for development of locally relevant information products. In the intervening years, smaller meetings will be held on a regular basis between selected working groups and managers/NGO staff.

B. Masters, PhD, post-doctoral students and local scientists trained in developing countries

Post-graduate and post-doctoral training will be a major component of all the Working Group research.

Wherever possible developing country students will be used to carry out work under the supervision of working group members. The level of involvement will be fully defined during the startup of each research component and will depend on the availability of suitable students. This could range from full scholarships to undertake work in the Institute of developed country members of the working groups, joint supervision between developed and developing country scientists with a proportion of the time spent in training within the developed country institute, or simply the incorporation of a component of a local student's research project into the local activities of the group, with the student benefiting from the advice and interactions of various working group members during field visits. A definitive list of developing country student involvement is not yet available, but initial plans envisage at least 10 masters, PHD and Postdocs being involved in the project. The sharing of at least two postdoctoral fellowships is also being considered in partnership with the International Society of Reef Studies.

C. Peer-reviewed scientific publications

Publication of the major results of all the research will be in peer-reviewed publications. The senior scientists involved in each working group all have excellent publication records and joint publications with developing country counterparts will be the norm for all research activities. The chance to publish with some of the most senior figures in each field will constitute an important capacity building component for both students and early career scientists in all groups. The publications will be supplemented by other reports and information briefs written for a more general audiences. A list of publications in peer reviewed journals generated so far by working group members during the course of Project preparation is attached.

D. Other activities by each of 6 WGs (training workshops, etc.)

In addition to the major workshops involving all working groups mentioned above, each working group will hold additional meetings and small workshops to familiarize local participants and stakeholders with the proposed work. This will also involve training of local personnel to carry out ecological surveys and certain experiments/measurements which require regular attention. Among those expected to participate would be technical staff and graduate students from local supporting institutions. In particular, the Disease Working Group will be training local Philippine personnel to carry out surveys for disease and to take samples for isolation and identification of pathogens.

III. Linking Scientific Knowledge to Management (US$ 4.1 M; Co-finance: US$ 2.1 M)

A. Responsibilities of various components of project

Each Working Group will develop a plan for engaging with managers and stakeholders. This has already been established for most groups and is set out in the Technical Annexes. This will be refined during a meeting with stakeholders during the first half of year 1. The plan will include a locally relevant process for communicating the results of the work to various stakeholder groups and for interacting with them in the interpretation and further dissemination of management relevant recommendations or information products. One member will be assigned a specific role to maintain communication with key contacts in each country during the course of the research. Formal and informal dialogues between stakeholders and working group members will take place on an ongoing basis. Wherever possible, suggestions for new research activities or additional components will be incorporated into the plans for subsequent years. Each working group will produce an annual non-technical report on the results and management relevance of the group's progress and achievements.

The Synthesis Panel will play a crucial oversight role to ensure that the research results of each group are

made available to managers, and other stakeholders in an appropriate format. The panel will oversee a central information coordination and dissemination project which will ensure that all results are properly stored, indexed and that technical and non-technical summaries are available in printed and electronic form to all stakeholders. The Synthesis Panel will also oversee the organization of the major information transfer and feedback workshops, involving all working groups and held at each active regional node. These will be facilitated by individuals with outreach and communication skills, and experience working in developing countries. During the first year the panel will also finalize policies on intellectual property and information access that will provide maximum flow of data and information while giving reasonable protection to researchers who need to publish their work before it enters the public domain.

B. Information Products and Information Coordination/Dissemination

In order to maximize the impacts of the project on managers, scientists, environmental NGOs and government agencies in coral reef countries, the results of the program will be output in a variety of formats and using a range of media. Peer reviewed papers will represent the highest level of scientific output and will ensure a high level of quality control on the results and conclusions. Non-technical summaries of the major findings will also be created by a contract science writer with experience working in developing countries. These will be further distilled into short briefs outlining the major results, setting out the policy implications, and listing possible management actions and policy options for consideration by relevant government agencies. The World Bank, as implementing agency, will use these policy briefs to inform its Country Dialogue with client countries and the preparation of country assistance and other strategies to guide its lending and non-lending operations. Such information will be used to promote reform in those economic sectors as well as macroeconomic policies which are responsible for local stress on coral reefs.

All summary data and information arising from the project will be entered into a central database together with a meta-database of all raw data holdings. This will form the core of an online information system similar in function to ReefBase, the coral reef information system operated by the WorldFish Center. In addition a comprehensive bibliography of papers relating to all aspects of the research program will be compiled and made available in print and electronic form to a all members and interested stakeholders. A selection of these will be made available as online documents for downloading and sharing amongst members. All information will be extensively cross referenced and searchable using keywords as well as through interactive maps. Summary information from data tables will be made available through an interactive query form and will output tables, graphs and reports. Photographs and remote sensing images obtained as part of the project will be stored in the database and made available for download using similar query and search interfaces. This program-wide information system will be closely integrated with the Decision Support and GIS facility which will be developed by the Modeling and Decision Support Working Group.

C. Modeling and Decision Support Working Group

The Modeling and Decision Support Working Group (MDS-WG) is focused on the development of a set of novel, state-of-the-art tools to improve coral reef management and education. It integrates the work of the other five working groups, and combines this with a broad range of social, economic, ecological and physical information in a land-to-sea, watershed-based framework. The research is centered on the development of Dynamic Decision Support Systems (DDSS), which will augment Geographic Information Systems with best-practice guides, expert systems, and scenario-testing models. The models will be aimed at identifying ranges of potential outcomes of management actions classified according to their probability of occurrence. The tools will initially be developed for Puerto Morelos, Mexico and Bolinao, Philippines.

The DDSSs prepared for these systems will be used as pilots for similar work on a greater number of reef areas in later phases of the project. The models will be made available across the Internet, via interfaces tailored to the public, policy-makers, resource managers, scientists and students of high school, college and graduate levels.

Thus, the Dynamic Decision Support System is designed to:

- Provide ready access to a broad range of existing information about the coral reef social-ecological systems.
- Provide an expert system, involving decision trees and other means to guide the user to a built-in "Best-Practice Guide", including case histories of similar management situations from coral reef areas.
- Provide spatiotemporal models that run scenarios many times, varying key behaviors and parameters to account for uncertainty. They will provide potential outcomes of low, medium and high probability in terms of the effects of a potential management decision on the environment and associated social and economic systems.

The DDSS will use a GIS system with simple expert systems, including standard decision trees, guiding the user to useful case-histories. It will be developed in 3 major stages: 1) Analysis and filling of information gaps required for the model; 2) Development of the model; 3) Field Validation of the model.

1. Gap analysis and Gap Filling

All available reports, publications, and data sets on the focal sites will be assembled. Initial critical information gaps, identified from prototype models, will be filled from other published studies conducted within the region. Information will be stored in GIS and relational databases which will be designed to be compatible with those of the Mesoamerican Barrier Reef GEF Project which use the same products.

Local data will be gathered to fill remaining critical gaps. This will include analysis of remote sensing imagery for land-use and deforestation, and towed diver surveys, transects, and visual census points for reef data. For social and economic parameterization, surveys will be conducted, including general interviews and formally randomized sampling using pre-tested survey forms. Wherever possible, data collected by other working groups will be used.

2. Model Development

A series of prototype models will first be developed, designed to highlight technical difficulties and potential inherent sensitivities in the mathematics and simulated interactions. This system will be reworked to a state-of-the-art online. A strong effort will be on user-friendliness and search efficiency. The system will include static layers depicting the reefs, watersheds, maps, oceanographic features, economic and social data. Much of the mapping of ecological and land/water features will be derived from satellite imagery. The system will also incorporate a best practice guide. This will be a collection of management actions and subsequent system responses from coral reefs around the world. The reports will be gleaned from the literature and from unpublished reports and invited write-ups.

Simple expert systems (Wright et al. 1993, Schmoldt and Rauscher 1996) will guide users through the best practice guide, as well as through the selection of options in the DDSS. The expert knowledge will be generated by coral reef experts and managers, and broadly peer-reviewed.

The major feature of the system will be dynamic scenario testing layers. These will be spatio-temporal outputs of underlying models, callable directly from the GIS as one would a static layer. User-defined options will be input from an adjacent window. The models will run many times for each scenario, producing statistics that will be displayed in non-spatial graphs and reports (below). The user will then have the option to display selected maps with the output information from averages of runs, extremes of runs, or specific case examples. Most of the models will be Agent-Based Models operating over the GIS framework. However, for hydrodynamics, hydrology and others, more widely established differential equation approaches will be used, with links to Agent-Based Models. The specific models to be developed are listed below.

- Hydrodynamic model
- Hydrological/land-use/erosion/pollution watershed model
- Ecological habitat spatial distribution/resilience model
- Coral bleaching sensitivity model
- Coral disease epizootiological model
- Remediation/restoration model
- Key fish and mobile invertebrates spatial distr. model
- Fishery production spatial distribution model
- Resource value/use spatial distribution model
- Income spatial distribution model
- Quality of life spatial distribution model
- Land & sea zoning/transportation/access model

3. Field Validation

Throughout the development of the DDSS, the models will require extensive field validation. The goal of the modeling will be to determine broad sets of outcomes of potential interventions based on assumptions about cause and effect relationships. Every opportunity will be taken to validate the intervention-outcome relationships when management interventions have been made. Additionally, much more thorough testing of the hypotheses about cause and effect relationships will be accomplished based on inference from social, economic, physical and environmental variability over time and space. Periodic sampling within all four of these disciplinary foci will yield multivariate data that will be analyzed using multivariate methods.

4. Management implications/outcomes

The tools will be designed to assist policy makers, managers and others to improve the management of coral reef systems. The DDSS will aid the decision-maker via improved access to information in terms of the local situation and in terms of prior experiences elsewhere. It will further provide assistance by helping the decision-maker to eliminate outcomes that are highly improbable and to identify problems that would otherwise be unforeseen. A major concern on coral reefs is the loss of ecological resilience. The DDSS will be designed to focus particularly on incorporating into its models state-of-the-art information on the ecological conditions and interactions associated with this problem, as well as the coupled human-environment relationships that influence and are influenced by those conditions. In the process, greater scientific insights into the problem will be facilitated.

5. Linkages with other WGs

All other working groups will provide information and data to the DDSS. Satellite imagery for Puerto Morelos and Bolinao from the Remote Sensing will be particularly important. Field surveys of coral and

other benthos, obtained by the Diseases, Bleaching and Remediation Groups will also be used to fill critical gaps in the models parameters. The dispersal and recruitment patterns observed by the Connectivity group will also be used. Each of the working groups will also make use of the model outputs as well as the input data layers as background ecological information relevant to site selection and interpretation of ecological results.

List of Targeted Research-related Publications
In Print, in press or in preparation

Bleaching Working Group

- **T.P. Hughes, A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C. Folke, R. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J. Keypas, J.M. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen, and J. Roughgarden.** 2003. Climate Change, Human Impacts, and the Resilience of Coral Reefs. Science Vol. 301 (August 15): 929-933.
- Nature, Vol 45, 28 Feb 2002: "Reef under threat from 'bleaching' outbreak"
- **R.P. Cooney, O. Pantos, M.D. Le-Tissier and J.C. Bythell**: 'Comparison of the molecular microbiology of black band disease in corals between the Great Barrier Reef and Caribbean' (Submitted).
- **LaJeunesse, Todd C., William K. W. Loh, Robert van Woesik, Ove Hoegh-Guldberg, Gregory W. Schmidt, and William K. Fitt:** Low symbiont diversity in southern Great Barrier Reef corals relative to those of the Caribbean (*Limnology & Oceanography*, Vol. 48(5), September 2003, *in press*)
- **Ove Hoegh-Guldberg, Ross J. Jones, Selina Ward & William K. Loh:** Is coral bleaching really adaptive? *Nature* **415**, 601 – 602, Feb 2002
- **B.E. Brown, R.P Dunne, M.S. Goodson, A.E. Douglas:** Experience shapes the susceptibility of a reef coral to bleaching. *Coral Reefs* (in press).
- **Gian-Reto Walther, Eric Post, Peter Convey, Annette Menzel, Camille Parmesan, Trevor J. C. Beebee, Jean-Marc Fromentin, Ove Hoegh-Guldberg, Franz Bairlein**: Ecological responses to recent climate change. *Nature*416, 389 – 395, Mar 2002.

Remote Sensing Working Group

- **Tiit Kutser, Arnold G. Dekker, William Skirving**: Modeling spectral discrimination of Great Barrier Reef benthic communities by remote sensing instruments. *Limnology & Oceanography*, 48, 497–510, Aug 2003.
- **P.J. Mumby** and eight co-authors. A Review of Remote Sensing for Coral Reefs. Submitted *Marine Pollution Bulletin*
- **Hedley JD, Mumby PJ, Joyce KE, Phinn SR** (2003) Spectral unmixing of coral reef benthos under ideal conditions. Coral Reefs (*in press*)
- **Hedley JD, Mumby PJ** (2003) Spectral unmixing and the resolution of depth from remotely sensed data of aquatic systems. Limnology & Oceanography 48: 480-488
- **Mumby PJ, Edwards AJ** (2002) Mapping marine environments with IKONOS imagery: enhanced spatial resolution does deliver greater thematic accuracy. Remote Sensing of Environment 82: 248-257

Disease Working Group

- **Drew Harvell, Charles E. Mitchell, Jessica R. Ward, Sonia Altizer, Andrew P. Dobson,5 Richard S. Ostfeld, Michael D. Samuel:** Climate Warming and Disease Risks for Terrestrial and Marine Biota, *Science*, 296, 2158-2162, June 2002.
- **C. D. Harvell and seven co-authors**. In prep. New Perspectives on International Impacts of Coral Disease.
- **Mullen, Harvell, Jordan, Ward, Alker, Smith, Petes**. submitted. Host range and anti-fungal

resistance of aspergillosis in three seafan species of the Yucatan. *Marine Biology*.

- **Ward, Lafferty, Harvell.** in prep. Proxies Reveal Increasing Impacts of Disease in the Ocean.
- **Ward, Harvell, Smith, Bruno, Rypien, Jordan.** in prep. A Test of the Disease as a Driver of coral Biodiversity Hypothesis.
- **Harvell, Pates and Peters.** in prep. Mechanisms of Coral Resistance to Disease. (Chapter contributions for a book edited by Eugene Rosenberg, in prep. *Global Coral Health and Disease*.)
- **Weil and Smith.** in prep. Local and geographic variability in disease prevalence at the species level in the Wider Caribbean.
- **Willis, Smith, Ritchie and Paige.** Prevalence of Coral Disease in Australia.
- **Raymunodo and Kacsmarsky.** Prevalence of newly described Philippine Coral Diseases.

Restoration and Remediation Working Group

- **L.M. Chou and ten co-authors.** A preliminary guide to coral reef restoration and remediation options for managers. Planned for December, 2003.

By Component:

Project Component - US$ million

Additional GEF Annex 3: Incremental Cost Analysis
WORLD: Global Coral Reef Targeted Research and Capacity Building Project

Context and Broad Development Goals

1. Context. Although they occupy only 0.1% of the ocean's surface, coral reefs are the world's richest repositories of marine biodiversity, and are the largest living structures on earth. Like their terrestrial counterparts, the rainforests, coral reefs support an array of environmental goods and services, whose ecological, cultural and economic value exceed our current capacity to quantify. Yet, despite their global significance, coral reefs are in decline worldwide.

2. The Global Status of Coral Reefs 2002 Report, lists two thirds of the world's reefs as under severe threat from the cumulative impacts of economic development and associated impacts of climate change. Even more recent reporting from the Scientific community (*Science VOL 301 15 August 2003*) stresses the now-global extent of coral reef decline.

3. The root causes of the deterioration of coral reefs have historically been attributed to direct human impacts, such as over fishing and destructive fishing practices, and chronic forms of near shore pollution, including sewage and sedimentation from poor land use practices. However, over the last several decades trends in climate-related episodes have begun to have significant impacts on coral reef ecosystems, and the combination of such events, combined with chronic forms of stress, are likely acting synergistically in the deterioration of coral reefs. The cumulative impact of threats to coral reef ecosystems is exacerbated by these historically rapid rates of changes in climate globally, which places enormous stress on the ability of coral reefs to adapt. That the negative trends appear to be observed in all coral reef regions of the world clearly indicate the global scope of the problem.

4. Calls for more effective conservation and more sustainable use of coral reef ecosystems have been a familiar theme in global forums, from the International Coral Reef Initiative, to the Convention on Biological Diversity (1995), the International Tropical Marine Ecosystems Management Symposia (ITMEMS I and II, 1998 and 2003, respectively), and most recently, the World Summit on Sustainable Development (2002). The WSSD Plan of Implementation identifies coral reefs as unique and vulnerable ecosystems that play a crucial role in the economies of Small Island Developing States (SIDs) and other developing states, and urges partners to: (i) implement the Framework for Action of the International Coral Reef Initiative (ICRI); (ii) implement the Jakarta Mandate on Marine Biodiversity of the Convention on Biological Diversity; and (iii) strengthen capacity globally to manage these ecosystems through science-based management and information sharing.

5. Many coral reef conservation and management initiatives have been launched in response to these challenges. As examples, the World Bank, in partnership with the GEF and others currently has over $270 Million in active or pipeline projects in which coral reefs are a significant focus of conservation/sustainable use management effort. The United Nations Foundation, through UNEP, has catalyzed the launch of the International Coral Reef Action Network, and several International Non-Governmental Organizations (e.g. the World Wildlife Fund, The Nature Conservancy, Conservation International) have launched programs in an attempt to reverse coral reef decline. However, the effectiveness of these interventions is undermined by a paucity of information about what determines ecosystem sustainability and resilience to major disturbance events in an environment of increasing and variable stress. This information can only come from robust empirical observation and research on

stress/response interactions, analysis of ecosystem drivers and threshold points. From such research it is possible to produce knowledge and to help national and local coral ref managers apply this knowledge by developing the tools and approaches needed to manage with credibility and effectiveness. Such systematic research must be targeted to management needs and of sufficient temporal and geographic scale to discriminate long-term trends from background noise and local ecosystem response from larger scale, potentially global effects.

5. Project Scope. Without the understanding of key ecosystem processes and how they interact with the range of stressors facing coral reefs today, management interventions, short of complete removal of the sources of stress, will continue to be largely guesswork. The precautionary principle is currently our best tool to counteract threats from economic development and climate change whose impacts we do not fully understand. This is, however, a blunt instrument which is both economically and socially costly, and hence rarely applied.

6. The alternative approach, which this project embodies, is to support coral reef management with World-class targeted research. This involves scientists asking the right questions whose answers can benefit management and then providing managers with the best available science-based answers to them, e. g., to identify major drivers or bottlenecks in sustaining coral reef ecosystem goods and services, or to improve the cost-effectiveness of applications of existing tools, like Marine Protected Areas and coastal and ocean zoning, and the use remote sensing and modeling to support decisions. Such targeted research may also lead to development and application of new tools, such as biotechnology, in the design of bio-indicators of reef stress or resistance to bleaching, and in the identification of pathogens and their pathways of transmission. At the macro scale, this might involve the development of new tools like genetic markers to reveal connectivity between reef systems or techniques to enhance natural recovery and restore reefs damaged from blast fishing or cyanide. This new knowledge, when disseminated and linked to decision-making, has the capacity to dramatically increase the effectiveness of current and future management interventions as well as improvements to policies at the national level. It also lends credibility and accountability to decision-making and has the potential to generate the political will needed to make tough trade-offs between conservation and intensive use. These are the development objectives of this project.

7. This Coral Reef Targeted Research Project will be the first phase of a long term coral reef targeted research program. The program will be implemented in phases; this Project's first five-year phase will initiate research in areas of the world with significant coral reefs and Bank/GEF investments. These include sites in Mesoamerica, East Africa, Southeast Asia, and the Southwestern Pacific. Research nodes will be established at existing institutions that have the capacity to develop into Centers of Excellence in the region, and that may serve as resources and information clearing houses to satellite sites (involved in collaborative research or management), within and between regions.

8. The Project has the following four main objectives and components:

a. Addressing Knowledge and Technology Gaps.

9. Over the past ten years, awareness of the importance of coral reefs has increased sharply, especially in light of their rapid decline in many regions, and their significance to developing countries. However, significant gaps remain in our understanding of some of the basic forcing functions and processes affecting coral reefs—to the extent that current management options are severely limited. The Project will systematically define information gaps, and prioritize them in an order of strategic importance to management, so that the resulting information and tools developed can lead to credible outcomes.

Furthermore, policies developed at regional and national levels will also be strengthened to improve legislation to sustain the products and services provided to SIDS and coastal communities by coral reefs.

10. This component of the Project is organized around six key themes and major research categories, which will be investigated by interdisciplinary teams of developing and developed country scientists. These themes were identified through extensive consultation over the course of project preparation to encompass the kinds of knowledge and management tools that underpin sustainability science for coral reefs. They include:

- The physiological mechanisms and ecological consequences of large area (or massive) coral reef bleaching, particularly in response to sea surface temperature anomalies, like the El Niño/Southern Oscillation episodes, and the potential consequences of their changes in frequency;
- The nature, severity and spread of coral reef diseases, some of which may be responsible for major shifts in the structure, function, health and sustainability of coral reefs;
- The importance of larger-scale ecological processes, and the physical and biological connections (or "connectivity") between coral reefs, whether within or between different regions. This also has direct bearing on the environmental conditions and key design factors needed to establish and sustain effective Marine Protected Areas (MPAs);
- The tools, technologies and efficacy of restoring coral reefs that have been severely degraded or destroyed, and the key organisms and environmental conditions to consider when rehabilitating a given coral reef environment;
- The application of advanced technology, particularly remote sensing, to refine information and enhance the rate and scale at which knowledge can be generated and applied. This includes the need to modify technology so that it can be practically deployed and sustained within developing countries;
- The need to develop decision support tools and scenario building which integrate economic development with bio-physical and other forcing functions to determine coral reef ecosystem response to (different kind and rates of) change or stress. Included in this type of analysis may be the impact of human stress on altering trophic relationships on coral reefs, particularly the relationship between nutrients, overfishing, and the overgrowth of corals by seaweeds and the reversibility of transistions between coral dominated and algal-dominated states. The development of models will incorporate the economic value of coral reefs, the socio-economic factors that affect the sustainable use of coral reefs, and the factors that inhibit translation of science into management.

b. Promoting Scientific Learning and Capacity Building

11. Currently, most coral reef research is based in universities and research institutions in the developed countries, while most coral reefs are located in developing countries. Rectifying this global discrepancy is the key mission of this project component.

12. In order to achieve this objective, the Targeted Research investigations will focus around four "Centers of Excellence" (COE) in four major coral reef regions (Western Caribbean (Universidad Autónoma Nacional de México), Eastern Africa (Marine Science Institute, University of Dar es Salam, Zanzibar, Tanzania), Southeast Asia (Marine Science Institute, University of the Philippines), and the central south Pacific (University of Queensland, Australia).

13. These COEs will serve as nodes for targeted learning and capacity building between developed and

developing country scientists -- to ensure that the information ultimately used by managers is regionally appropriate, and to train local scientists so that they can respond to future developments. Through twinning arrangements between various universities and research institutions, coral reef scientists will exchange with partner institutions to share cutting edge techniques e.g., the identification of coral pathogens, measurements of metabolic stress linked to specific environmental stressors, the use of genetic markers to track larval dispersal and connectivity, and application of agent-based modeling techniques to simulate coral reef ecosystem response to various forms of stress. The Targeted Research Project will support a series of workshops each year which will bring researchers in the various working groups together to orient field research, brief each other on findings and based on these results, modify and design the next phase of research.

c. Linking Scientific Knowledge to Management and Policy

14. A third major objective and outcome of this Targeted Research Project will be to improve global predictive capability in assessing impacts to coral reef ecosystems, in the face of cumulative stress from increasing coastal populations, changes in climate and other uncertainty. The targeted investigations are designed to feed into decision support systems for managers, policy makers, and other stakeholders.

15. The results generated from the targeted investigations will be formulated for application into management and policy contexts. Over the course of project implementation, the information and tools produced will be disseminated as knowledge products to enhance the management approaches and interventions. These products may range from in-situ diagnostics (for example, disease assessment and bio-indicators of specific forms of stress and metabolic response in coral reef organisms, to markers for larval recruitment indicating source and sink reefs) to remote sensing products and applications to assess the state of coral reef health. In addition to these tools, a series of management and policy briefs will be developed periodically by the Steering Committee and released to targeted audiences. These audiences include the World Bank Country Directors and Country Assistance Strategy (CAS) and Poverty Reduction Strategy (PRS) teams, GEF project teams, policy-makers, and member of regional and global fora (e.g, the IPCC, CSD, ICRI, SBSTTA, Regional Seas Conventions).

16. Links will be made between research results and management efforts in the four regions. Each Center of Excellence will serve as the conduit of information to satellite sites and various user/stakeholder groups (including NGOs and others involved in MPA management, coastal zone management and marine regulation, national and community-based coral reef management activities, and ecosystem monitoring efforts. NGOs active in the region, represent a particularly cost-effective means to communicate findings to managers and help convert them into low-tech solutions for direct application to developing country management needs. These include tool kits for managers, as well as those involving bio-indicators to assess stress in key reef species. At the other end of the spectrum, high level audiences will be kept abreast of research findings through publications of each of the working groups; through Steering Committee briefings, and in the form of periodic management and policy briefs.

17. The project component's main stakeholder and beneficiary groups will be both developing and developed country scientists who—for the first time in history for this scientific community—will have an opportunity to collaborate on address problems at a regional and global perspective that would not have been possible up until this point in time. It is anticipated that this project will result in a considerably strengthened institutional and human resource capacity, awareness and an improved, global information base from which the Centers of Excellence, visiting country scientists, managers, and academic institutions and agencies will benefit.

18. Additional target beneficiaries are members of the global community who also benefit from the biodiversity of coral reef ecosystems and services. It is anticipated that the project will result in significant gains in biodiversity conservation and sustainable development knowledge, information, awareness, income and non-monetary economic benefits. Finally, the GEF will also be a beneficiary of this project by gaining new insights into the best application of future GEF funding as applied to specific management and conservation options for coral reefs and related marine resources within its member countries.

d. Project Execution and Administration

19. Given the global extent and the multidisciplinary nature of this undertaking, a carefully designed project execution and administration component is a critical part of the overall framework. The project involves renowned researchers from over 50 institutions who will carry out integrated, coral reef targeted research projects in four regions around the world. In addition, these scientists will work together to ensure that local capacity in the regions in which they work will be built over time, so that local scientists can benefit.

20. The successful execution of the project will be contingent on an implementing arrangement with committed individuals and institutions, a good governance structure, fiscal and managerial responsiveness, and sound financial management. This involves the coordination between the various working groups, and the related field work, the Steering Committee, the Centers of Excellence, the distillation of relevant information and its appropriate communication in the contexts of scientific peer review, management application, policy and sustainable development. As part of the project's preparation a range of institutional models have been considered and evaluated. A model has been chosen that balances the need for speed and efficiency in supporting the on-the-ground targeted research, with the need for technical and fiscal accountability in reaching the project objectives and goals.

21. The project will be managed by a Project Executing Agency (PEA), which will liaise with all of the Technical Working Groups, regional Centers of Excellence, and individual project staff when necessary. The PEA will have a fully dedicated staff to oversee project implementation, outreach and communication activities, and future planning (including development activities to identify future co-financing and new partnerships). Such a staff will include, at a minimum, a senior level Executive Director, a Project Coordinator, an Outreach and Communications Specialist, and a Financial Manager. These will be full time positions, preferably working out of the same centralized project office. In addition, the PEA will hire, as necessary, short term consultants to 1) design workshops to integrate the research efforts of the Technical Working Groups, 2) oversee capacity-building efforts within the regions, and 3) disseminate synthesized results of targeted research to recipients involved in coral reef management, such as decision-makers, non-governmental organizations, and donor organizations.

22. In addition to the core management group that works together out of a centralized location, one or more data managers will be necessary. Such staff will not only manage the databases, but also develop and implement mechanisms for accessing such data -- for the scientists involved in the project and for the public at large. The need for such a position will of course increase through the life of the project.

23. The Technical Working Groups will be responsible for planning detailed research activities in each specialty, including choices regarding individual projects and institutions, as well as budgetary decisions involving resource allocations and procurements. Chairs of the Technical Working Groups will develop and submit annual work plans to the PEA, to be reviewed and approved by the Steering Committee. Each chair will also be responsible for evaluating progress made towards the stated goals of the Technical Working Group which he/she heads.

Baseline Scenario

24. *Current Situation*. In the absence of GEF assistance for this project, the scientific community will pursue various coral reef targeted research investigations within limited and uncoordinated subject areas and geographic scope and using a variety of methods. There will be some collaboration between developed and developing country scientists, and a modest amount of additional scientific capacity will be developed in the countries and regions where most coral reefs are located. Some of this baseline work may receive other forms of support from public and private foundations and academic institutions, and some would be undertaken (in the case of developing countries) through government institutions' own limited financial resources. In effect, the baseline work is largely compartmentalized within a country or sub-region and will focus on disparate scientific aspects of this global problem. While some scientific progress will continue to be made, little coordination of the research and little systematic dissemination of the information it produces, within a multi-disciplinary context, would occur.

25. Given the uncoordinated aspects of current research among investigators, their institutions and countries, and the inadequacy of resources to address problems with a multidisciplinary approach, it is almost certain that coral reefs within each of the target regions will continue to be degraded and global biodiversity values will continue to be lost unless significant, targeted actions are taken within a coordinated operational framework to supplement the current baseline.

26. *Scope of the Project's Baseline Scenario.* Based on an analysis of current plans for investigative activities under the baseline scenario, the following table illustrates where specific resources and activities are most likely to take place. Baseline expenditures on conservation-related activities are largely regionally focused, and so the baseline expenditures primarily generate limited local benefits, not global ones.

TABLE A 4.1 – SUMMARY OF BASELINE CORAL REEF RESEARCH ACTIVITIES

NO.	NATURE OF INVESTMENT	GEOGRAPHIC FOCUS	Budget amounts over 1-5 years (US$Millions)
a.	Regional Environmental Monitoring and Information System	Mesoamerican Barrier Reef System (Mexico, Belize, Guatemala, Honduras)	4.4
b.	NOAA Coral Reef Watch Program	Caribbean, Northwest Pacific – US	8.0
c.	Ecology of Infectious Disease within Coral Reefs (NSF Grant)	Caribbean	0.25
d.	University of Queensland. Coral Reef Climate Change-related investigations. Development of specific indicators related to coral bleaching.	South Pacific, Mexico	1.2
e.	Remote Sensing – methods testing for field sampling and risk mapping	Caribbean, Palau	0.175
	Total		**14.0**

27. *Costs*. Over a five year project period, the total expenditures under the Baseline Scenario would be approximately USD$14 Million. These are constituted as follows:

a. Regional Environmental Monitoring and information management system in the Mesoamerican Barrier Reef System.

Through a project funded by the GEF and World Bank the Mesoamerican region is developing a long term program for protection and sustainable use of the barrier reef system bordering Mexico, Belize, Guatemala and Honduras. As part of the project a sub- regionally focused monitoring and information management system is being developed to ensure that:

- monitoring techniques are appropriate, cost-effective and responsive to the information needs and monitoring capacity of each country, and that
- monitoring protocols are compatible within the region to allow for cross-country comparisons and integration of data into a regional assessment of ecosystem health over time.
- only a small proportion of resources is allocated to targeted research and field investigations, with the bulk of effort going toward monitoring and reporting.

b. NOAA Coral Reef Watch Program

The US National Oceanic and Atmospheric Administration has developed a program that focuses on technological applications for coral reef management. NOAA Scientists have developed experimental algorithms using satellite sea surface temperature imagery to identify regions of concern for coral bleaching events. With the experimental algorithms, NOAA provides a rendering of sea surface temperatures interpreted experimentally for the study of coral bleaching. In addition to this work, NOAA provides a number of websites and information products focusing on coral reef database management, integrating biological data from the reefs with interrelated chemical, biological, and physical data of surrounding marine areas. These data include measurements of coral reef taxa occurrences, numbers, life stages, pathology, productivity, sea water chemistry, turbidity, temperature, salinity, currents, bio-optical data, and substratum features. NOAA provides significant support to the United States Coral Reef Task Force and its domestic agenda for the protection of state and territorial coral reefs, but a significant amount of its work and resources also focus on the Caribbean basin and the Pacific Ocean, with an increasing interest in supporting international efforts.

c. Ecology of Infectious Diseases

Based on a five year grant from the (US) National Science Foundation, a number of investigators, some of whom are working group members, have received grant funding to further study the nature and extent of diseases affecting hard corals, and particularly sea fans, within the Caribbean Basin. The results from this work will contribute to more specific knowledge on the cause and effect of specific diseases or syndromes within this region.

d. Coral Bleaching, Climate Change and Development of Indicators

The University of Queensland has received grant funding from a number of sources to conduct a range of studies related to coral reef bleaching and the consequences of thermal stress on coral reefs within the Pacific and to a lesser extent, the western Caribbean (Yucatan Peninsula in Mexico). Results from this work will lead to the development of some indicators, but this work would be geographically limited in research and application of results. It would not have the potential to influence policy decisions which may impact on coral reefs

e. Remote Sensing methods for field sampling and risk mapping

Academic institutions, such as the University of Waterloo (Canada), University of Exeter (U.K.) the Australian Institute of Marine Science and others have committed resources to field test a number of approaches for coral reefs using remote sensing technology. In particular, the prospects of developing maps for areas that may be at higher risk to coral bleaching is being developed using Landsat imagery to proxy local bathymetry is being examined. Also, field testing of the potential plot sizes for long term monitoring using remote sensing is being developed.

28. *Benefits*. The benefits of the Baseline Scenario can be characterized as modest. At least some ongoing research and progress will be made with respect to various scientific investigations. However, these will be uncoordinated within any adaptive science framework (such as this project), and will be of limited benefit, especially if results remain within the confines of only one or two regions. Furthermore, results will be of limited global benefit within any management or policy context given the isolated nature and lack of information coordination of results. Of the activities defined,work within the Mesoamerican Barrier Reef System)would likely have the greatest spatial impact with respect to management application.

Global Environmental Objective

29. The Project's Development Objective and the Global Environment objective are to fill critical gaps in our understanding of what determines coral reef ecosystem vulnerability and resilience to a range of stressors--from climate change to chronic and acute forms of localized human impacts-- and to use this knowledge to strengthen management and policy globally for the benefit of coral reefs and the communities that depend on them. This will be achieved through targeted investigations involving networks of scientists, in consultation with managers, and the dissemination of knowledge within and across regions. The use of four major coral reef regions is an important aspect of this work, as it provides the opportunity to examine—and potentially replicate the findings—whether the factors affecting coral reefs are more local in nature or are global in extent, and how results can be used to strengthen future management options. The results generated over the life of this project will also significantly contribute to the GEF's ability to apply the best use of its limited resources in future conservation efforts where coral reefs and associated ecosystems are involved. A related objective is to build capacity for science-based management of coral reefs in developing countries where the majority of reefs are found.

GEF Alternative

30. *Scope*. The proposed GEF Alternative aims to develop a global adaptive science framework to allow scientists to investigate key unknowns regarding ecosystem drivers and how they interact with various forms of anthropogenic stress and climate change to determine vulnerability or resilience of coral reef ecosystems to these major forms of environmental "disturbance." The targeted research has been carefully designed in specific areas of study by the various working groups, to test hypotheses relevant to management decision-making and to inform end-users of the implications of the results so that they can be readily applied. The project scope of the GEF Alternative includes the project components summarized above.. The GEF alternative will mark the first time in history within this scientific discipline that a strategic and coordinated set of investigations—designed within an adaptive framework— will be organized and executed on a global scale. The four major coral reef regions were selected based on the prospects of establishing Centers of Excellence within important areas where investigations can be successfully staged, and where there are significant opportunities for sharing knowledge and extending scientific capacity and learning.

31. *Costs*. The total additional expenditures associated with the GEF Alternative are estimated to be about US$27.6 million; these are summarized in Table A4.2 The GEF Alternative would involve expanded and new activities as described in the project components section above, and are summarized below:

Table A4.2

Component	Indicative Costs (US$M)	% of Total	Co-financing (US$M)	% of Co-financing	GEF financing (US$M)	% of GEF Financing
1. Knowledge & Technology Gaps	14.0	51	8.5	51	5.5	50
2. Promoting Learning and Capacity Building	6.0	22	3.0	18	3.0	27
3. Linking Scientific Knowledge to Management	4.1	15	2.1	13	2.0	18
4. Project Administration	3.5	12	3.0	18	0.5	5
Total Project Costs	**27.6**	**100**	**16.6**	**100**	**11.0**	**100**

32. *Benefits*. The GEF Alternative will achieve all the benefits from the Baseline Scenario, but will enable further global benefits to be achieved, which can then be applied regionally and locally within appropriate management contexts to achieve additional regional/local benefits. In addition to the Baseline benefits, incremental benefits to the global community include the ability to conserve and sustain globally significant and representative biodiversity within each of the four regions, and to understand globally important drivers and trends in coral reef ecosystem health and to test and apply management options that may be broadly applied to mitigate impacts at the local and broader scales.

33. The GEF Alternative also provides institutional benefits that remove a number of the barriers to long term biodiversity conservation in these ecosystems. These institutional benefits include the following:

- *Strengthened links between science and policy for substantive and sustained change in behavior(public sector, corporate and local governance) in favor of coral reef ecosystems f Coral Reef Ecosystems*. The involvement of the Bank in promoting policy reforms based on reliable science, through country dialogue with clients and through its convening power in international for a will advance this outcome.
- *Development of protocols for the design of for more effective MPA networks and other and decision support tools* . Under the Baseline, "on-the-ground" experimental work, field testing of tools and interventions to enhance management in light of research findings, and decision support tools to help policymakers visualize the results of various development options is unlikely to occur. Under the GEF Alternative, by contrast, the communication and outreach activities designed to directly link science to management will educate stakeholders and help ensure that decisions are informed, and tradeoffs clearly spelled out. This will discourage short-term decision-making and increase the prospect for consistency in policies across sectors which have potential impacts on coral reefs.

34. *Domestic Benefits*. It is estimated that incremental domestic benefits of about US$4.00 million will be realized in the GEF Alternative case. These benefits are associated largely with the Centers of Excellence, and with direct interventions supported through the targeted initiatives in the GEF Alternative. Other indirect benefits may also be realized through improved project review and determination of future

components, based on the knowledge gained from the findings. Also, ecosystem management (e.g., improved watershed management, enhanced local existence values) but any incremental economic benefits from these improvements have not been estimated or included here; they are acknowledged to be one of the justifications for some level of Baseline support as a whole and for some further contributions towards the incremental costs identified under the GEF Alternative.

Incremental Costs

35. The total expenditure under the Baseline Scenario is estimated to be US$14.0 million while the total expenditure under the GEF Alternative is estimated to be approximately US$41.6 million. The incremental expenditures (costs) under the GEF Alternative are therefore US$27.6 million for the first phase project.

36. Of the incremental expenditures (costs) of US$27.6 million, the GEF is requested to fund US$11.0 million; the balance will be funded by other donors and stakeholders.

Table A4.3 – coral reef targeted research and capacity building

Incremental Cost Determination

(US $ million) [2003$]

Component	Category	Cost	Regional / Local Benefit	Global Benefit
A. Knowledge & Technology Gaps	Baseline	US$10.75	Specific areas of inquiry (not necessarily tied to adaptive or applied science) will continue. Some regions and localities will benefit from the findings.	Some benefits based on information products or tools that might be applied in more than one region (e.g. NOAA SST data products, indicators from Disease Research, UQ)
	With GEF Alternative	US$24.75	Improved coordination of priority unknowns (using similar methods) targeted within four regions and cross-referenced where possible. Sharing of methods, investigative techniques and information products.	Strategic uncovering of priorit unknowns through an adaptive scientific approach related to t sustainability of coral reef ecosystems through improved management and policy optio
	Incremental	**US$14.00**	–	–
B. Promoting Learning and Capacity Building	Baseline	US$1.00	–	–
	With GEF Alternative	US$7.00	Enhanced monitoring and information exchange permitting adaptive management. Efficient delivery of project funds, and evaluation of progress. Demonstration of financing models that potentially will be transferable to other protected areas, with concomitant	Enhanced information exchan between developed and developing country scientists. Efficient coordination of implementing institutions, and monitoring of progress.

			efficiency gains.	
	Incremental	**US$6.00**	**US$**	–
C. Linking Scientific Knowledge to Management	Baseline	US$2.30	Improvement of monitoring and information across a specific region (i.e. the MBRS region in the Caribbean)	–
	With GEF Alternative	US$6.40	Improved communication of targeted information across multiple regions and disciplines. Working Groups to specifically work with management interests to improve management options and approaches.	Improved protection of key globally and regionally threatened ecosystems. Translation of targeted researc to management and policy. Enhanced opportunities to engage in meaningful discussi with other disciplines (economics, law, sustainable development).
	Incremental	**US$4.10**	**US$0.00**	Not estimated.
D. Project Administration	Baseline	US$0.00	–	–
	With GEF Alternative	US$3.50	Establishment of Centers of Excellence within four regions to serve as learning centers and magnets for each Region.	Coordination of global efforts adaptive science to benefit management and policy. Efficient delivery of project funds, and evaluation of progress.
	Incremental	**US$3.50**	**US$**	–
	Baseline	US$14.00		
Totals	With GEF Alternative	US$41.60		
	Incremental	**US$27.60**	**US$0.00**	–

Additional GEF Annex 4: STAP Roster Technical Review
WORLD: Global Coral Reef Targeted Research and Capacity Building Project

"World investigation of localised stress and compounding effects on climate change on sustainability of coral reef systems" a targeted research project submitted by the World Bank

Sent to GEF on September 9, 2003

The STAP and the GEF Targeted Research Committee is very pleased to have had the opportunity to review the World Bank's Coral Reef Targeted Research Proposal scheduled for submission to the GEF Council in November 2003[1]. The Research Committee realizes that this project should have been at the time of pipeline-entry/PDF-B stage and appreciates the opportunity of being able to review it at this stage. In the future, the Research Committee very much hopes the process is successfully in place to support their capacity as committed scientists and reviewers of GEF targeted research proposals at the appropriate stage. The Research Committee trusts that its concerns on this coral reef targeted proposal will be addressed in the final documentation Some members of the Research Committee would like to reserve the right to send in more details comments at a later stage, whilst others have incorporated them here..

Overall, this is a well-conceived targeted research (TR) that is addressing the stresses that are affecting the coral reefs of the world. Its basic approach is well stated and the outcomes it is seeking have the potential to advance our understanding of the various stresses and their impacts on coral reefs. However, as written, we have a few concerns that make us uncertain as to whether the TR will deliver what is being promised. We have summarised our concerns below and they cover aspects of choice of the sites, institutions and individual scietists, scientific management and leadership, the transfer of the scientific information into management actions and comments on the proposed work by each of the Working Groups. Where possible, we have made suggestions that could be implemented to overcome these. We very much hope they can help strengthen the proposal and achieve the needed outcomes of this TR.

1. **The choice of the specific sites is not clear and should be clarified**. It is not clear as to why the specific sites mentioned were chosen for the research (and neither is the choice of individuals/institutions – see below). In an ideal world, the project would be carried out in sites that were representative of different coral reef systems, types of sediments, eutrophic impacts, stresses, spatial characteristics (eg. region and current systems) and biodiversity**.** Why are some regions excluded, eg. the insular Caribbean?

2. **The synergies between the Working Groups, and the way stresses are being addressed at any of the selected site, need to be clarified.** From the documentation presented, the synergies between the Working Groups are not clear. It appears that the multiple stresses that the project emphasises are not being addressed at all the sites. We would have assumed that this would have been one of the priorities and strengths of the project. From Appendix 6 it is hard to see what is going to be researched at what site. It would be extremely useful to present a site/activity table. This would really bring out if many of the stresses are indeed going to be addressed at the various sites. We realise that the technical appendices do provide more details for much of the work, but essentially address the issues in that working group and not across the working group.

3. **Plans should be developed to expose the project to a wider scientific scrutiny and seek their collaboration where needed.** In addition to the selection of sites, how and why certain individuals (especially team leaders) were chosen is not clear. The project should ideally have involved a wide

range of scientists and institutions from developing and developed countries and at least attempted to involve the best experts in those regions. We appreciate that this is not an easy task (both due to difficulties in identifying the best experts and the possibility of not being able to attract their interest and time). Given the stage of the project, we would like to encourage the proposed activities be reviewed more extensively by internationally recognised experts involved in coral reef research and seek their collaboration/involvement when necessary. A possible mechanism might be through a workshop in conjunction with a web-based discussion or a large international coral reef conference, so there is a wider exposure of the proposed activities and an extensive review. The STAP can also suggest experts from the developing and developed world.

4. **The different working groups work needs to be brought together under strong scientific leadership**. From the present draft, it is not clear that the Synthesis Panel and its chair would be able to bring the multiple stresses and the work at the various sites together even with an external chair. The Working Groups state that the other working groups would provide the information, data or expertise, but again, from the description given, it is not clear how this is going to be done – what are the questions that would be addressed and how would the information be brought together. Thus, the role and the value added of the Synthesis Panel needs to be clarified, in addition to the synergies between the Panel and the Working Groups.

5. **The project should state how it is building on existing information**. It is not clear from the proposal on how the Project will interact and benefit from the existing GEF interventions which includes a coral reef management component. This should be further elaborated in the proposal. It is even more intriguing that there is little or no mention of how the project will build on what has already been done by institutions such as, ICRAN, ICRI, ICN, NOAA, others involved in the insular Caribbean and the Cooperative Research Centre for Reefs in Australia. These institutions and others can also become potential collaborators and their existing resources and networks can become part of information dissemination, e.g., as part of the learning exchanges process, the data generated can also be distributed via nodes such as SIDSNET, which already has nodes in the Caribbean and the Pacific.

6. **There appears to be lack of consultation, needs analysis and engagement of the potential managers**. We do not see evidence that the management action will result from the scientific findings. Is there evidence that the managers are looking for 'science-based' solutions? Have they been consulted (i.e. user needs assessment done) and if so what were the outcomes? Have the managers had information presented to them by individuals or institutions involved before and have the managers taken action? There is no clear mechanism presented on how the scientific information will result in management actions.

7. **Management implications/outcomes are weak in all the working groups and need to be strengthened**. Linkages to other working groups are weak, including data/information and methodology transfer. Further information has to be presented to really demonstrate the mechanism for the transfer of the information to the mangers and its subsequent use. Section D, project rationale, does not mention the underlying causes. The management options should surely have to consider these before any "new" management strategies are put into place.

8. **We encourage the project to incorporate the *active* involvement of local communities from the beginning**. The approach taken at each of the sites appears to be very top down. We have seen little or no mention of the local communities that do manage and rely on many of the coral reefs of

the world. In some cases, we hope that they have people who have already been doing work on the ground as otherwise it is going to be very hard for the scientists and managers to walk in and do the work (e.g. in Papua New Guinea). Therefore, an initial stakeholder analysis would help in identifying and engaging the local communities.

9. **We are concerned about the participation of developing country scientists and the funds that will be allocated to them**. It would be helpful to indicate what is the ratio of experts from developing countries participating in the research, and what is the proportion of funds being allocated to developing countries.

10. **There appears to be a lack of post-intervention follow-up** and needs to be stated clearly. In terms of GEF global environment impacts, it is important to identify follow-up strategies. It seems to be missing entirely in the documentation. Further clarification is needed on what entities would follow up after the interventions? How would the follow-up occur?

11. **Some of the assumptions being made need clarification and testing**, (e.g. disease and the interaction with water quality is too simplified and generalised) and the appropriate Working Groups need to add that this will be tested. We feel that the project should point out the challenges and also the assumptions that apply to the replicability and transferability of the results.

12. **The summary of the proposed work by some of the Working Groups (see below) is excellent, but some others need to be strengthened both in terms of the methodology and perhaps the experts involved**. In particular we would like to highlight our concerns about Modelling and Decision Support Working Group and within that "Field validation". Field validation is a a critical aspect and needs to be considered in more detail than in the cursory manner presented here with (both within the main project proposal and in the Technical Annex 1). There is no indication as to how field validation will be undertaken, and no consideration of temporal and spatial scales etc.

More specific comments on the Working Groups

Our comments are based on the Annexes in the main document but we have also checked in the six Scientific Annexes provided. The quality of the documentations in these annexes seems to vary considerably. Again a strong scientific leadership for the whole project could help overcome this.

Some comments across the working groups are:

a) Scaling issues: Some of the information (e.g. IPCC scenarios) are available mostly at the global level, and yet the coral abundance, reef biodiversity etc is a t local and at best regional level. How would these be incorporated into the models?
b) Some of the modelling work mentioned in various work in the appendix is hard to do on land let alone an "open" system as that of coral reefs. We are not convinced that enough thought has been given to this ciritical section in all the working groups.
c) Only $3.0 million are allocated to "linking scientific knowledge to management", the same amount that is allocated to project administration. If the former is an important goal of the project, is this level of funding proportionately adequate? Perhaps the team might wish to revisit this funding allocation.

Specific comments on each of the working groups proposed work:

1. Bleaching Working Group: has some weaknesses. Some parts of the summary of the proposed work are excellent, however, other portions of the summary are less thorough, and give the

impression that little or no work has been done in the three activities listed in the first paragraph. We can only assume that since some of the processes involved, eg. changes in physiology to individuals reef systems, globe, are long-term that data needed on this would be somehow (through individuals and institutions involved?) be incorporated in the project.

2. Diseases Working Group: overall good.

3. Connectivity – various issues need to be improved, such as:
   a. There is not enough evidence to indicate that what is proposed is achievable in the defined time frame.
   b. It is not clear as to what techniques will have to be developed and which ones will be further expanded.
   c. How long would it take to do develop the tools to identify and monitor stress and would these techniques be easily and quickly transferable to the other regions?
   d. Is any of the information transferable to other regions and coral reefs with different history, biodiversity and set of stresses?
   e. Are the researchers concentrating on "keystone species" so they may obtain a good understanding of the critical processes?
   f. Is there a logic for choosing to concentrate on lobsters, groupers and snappers?

4. Restoration Working Group: well presented summary of the intended work, although again it would have been useful to say if pilot or other work suggests that the experimental work being suggested can be done over the spatio-temporal scale of the project.

5. Remote sensing Working Group: this seems to promise a great deal and we are not sure if it can deliver. Some of the techniques are a challenge in land-based systems and we are not convinced that these can be done in the coral reef systems. Further information on how the project team plans to address this would be useful.

6. Modelling and Decision support Working Group: this is the weakest WG in terms of the information presented. We are not sure if there is sufficient data available to develop an expert system. What are some of the challenges and can they be overcome? How will field validation be done? This is not trivial and should be clarified (see point 13 above). 12 major sets of models are being proposed and it is not clear how they will be integrated; there will be challenges in terms of information available and their spatio-temporal scales and yet this does not come across in the summary presented. We are not convinced that the research will lead to definite management implications

Some minor points on the main project proposal

- Section B, page 2 onwards. It would be worth mentioning climate variability as well as climate change is being considered; is "unprecedented" bleaching and not "unprecedented mortality" on page 3. The section does need to mention the temporal aspects and the potential time lags that might be of relevance to the coral reef systems
- Would the TR really lead to a "new generation of trained scientists" (page 20) in 5 years?

Response to STAP Roster technical reviewer's comments

(in italics)

1. The choice of the specific sites is not clear and should be clarified. It is not clear as to why the specific sites mentioned were chosen for the research (and neither is the choice of individuals/institutions – see below). In an ideal world, the project would be carried out in sites that were representative of different coral reef systems, types of sediments, eutrophic impacts, stresses, spatial characteristics (eg. region and current systems) and biodiversity**.** Why are some regions excluded, eg. the insular Caribbean?
As a result of the Block A consultations which engaged both scientists and managers, a conscious decision was made to limit the research to 3-4 key coral reef regions of the world during the initial five year phase. These regions were selected on the basis of where there were already significant GEF and other investments in coral reef management; where there was the beginning of a critical mass of coral reefs scientists and infrastructure to support establishment of a regional node (which could evolve into a Center of Excellence for coral reef research), and with support from the Project could facilitate research and capacity building at a number of satellite sites. The research nodes in these regions were carefully selected in coral reef ecosystems where considerable baseline data was already available and where resident researchers were engaged in research that could both contribute to and benefit from the targeted research objectives. (See Brief Section E.4.1)

Under ideal circumstances and significantly larger financial resources, this project would have greater spatial replication and site representation within each of the regions identified, and would reflect some sort of stratified random sampling design. However, there will never be enough financial resources to conduct the kind of spatial replication that would be required to generate rigor and power in a statistical context (i.e. drawing inference over a sampling universe within a given region). As an alternative, this project has approached the targeted research with a case-study model, whereby a limited number of study sites have been identified, in which a suite of investigations around key themes is carried out and the information integrated at each site. Results will be compared across sites, where possible, to assess what impact/response relationships may be global in scope as opposed to regional (in terms of cumulative impacts) or even local in scope. It is legitimate and necessary to focus at the outset on a smaller number of sites until the effectiveness of the research model(s) can be demonstrated.

It is the project's intention to expand the number of sites as the Project progresses through successive phases and the working groups move toward filling critical information gaps through time. This is why the Targeted Research has been conceived as a 15 year program. Sequencing is essential in light of the human and financial resources available and to allow consolidation of results and reformulation of hypotheses before expanding into new regions and sites.

2. The synergies between the Working Groups, and the way stresses are being addressed at any of the selected site, need to be clarified. From the documentation presented, the synergies between the Working Groups are not clear. It appears that the multiple stresses that the project emphasises are not being addressed at all the sites. We would have assumed that this would have been one of the priorities and strengths of the project. From Appendix 6 it is hard to see what is going to be researched at what site. It would be extremely useful to present a site/activity table. This would really bring out if many of the stresses are indeed going to be addressed at the various sites. We realise that the technical appendices do provide more details for much of the work, but essentially address the issues in that working group and not across the working group.
The suggestion of a site/activity table to lay out what investigations will occur at each site and where potential synergies between WGs lie is an excellent idea and will be incorporated into the Project Brief prior to final submission in November (see Section C1 addressing knowledge and technology gaps). As noted above, however, the need to concentrate investigations in a limited number of sites and to sequence the work in line with proof of concept, resources and logistics, has determined the initial scope and geographic focus of the research in phase one. As a result, not all Working Groups will be working at all sites simultaneously in the initial phases until demonstrations can be completed and then scaled to

other locations. Nevertheless, there is significant scope for synergy between the various working groups, and maximizing these opportunities and integrating information (especially at different scales) is a foundation of the model, and will be one of the main responsibilities of the Synthesis Panel to see that this occurs. This is a major strength of the proposed investigations and an example of the high value added of this approach to targeted research.

The Synthesis Panel has only been able to meet twice thus far during the Block B phase, but a third meeting is being planned in December 2003 to coordinate field work and to confirm procedures for the sharing of results in real time. In the meantime, there have been many working group meetings in which representatives from other working groups have attended. This has led to a more coordinated approach to the development of the WG research agendas and the sequencing of fieldwork, as reflected in the draft technical annexes. The construction of a table to clearly indicate who is doing what where, will help define this more clearly in the Brief and in the Project Implementation Plan.

3. Plans should be developed to expose the project to a wider scientific scrutiny and seek their collaboration where needed. In addition to the selection of sites, how and why certain individuals (especially team leaders) were chosen is not clear. The project should ideally have involved a wide range of scientists and institutions from developing and developed countries and at least attempted to involve the best experts in those regions. We appreciate that this is not an easy task (both due to difficulties in identifying the best experts and the possibility of not being able to attract their interest and time). Given the stage of the project, we would like to encourage the proposed activities be reviewed more extensively by internationally recognised experts involved in coral reef research and seek their collaboration/involvement when necessary. A possible mechanism might be through a workshop in conjunction with a web-based discussion or a large international coral reef conference, so there is a wider exposure of the proposed activities and an extensive review. The STAP can also suggest experts from the developing and developed world.

This comment suggests that the STAP was not aware of the considerable consultation and vetting within the scientific community that went on prior to and during the Block A Phase. The need for a Targeted Research program for coral reefs was first conceived in response to the 1997-98 El Nino-mass bleaching event, and presented at the first Inter-tropical Marine Ecosystems Management Symposium (ITMEMS) in November of 1998. After positive initial feedback and, following a favourable concept review by the STAP Research Committee in place at that time, a PDF Block A grant was obtained. The PDF A was to support systematic consultations with the scientific and management communities in conjunction with major coral reef fora, such as the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring and Restoration, 1999 in Fort Lauderdale, Florida, USA; the International Workshop on Coral Reef Bleaching in Riyadh, Saudi Arabia, 1999; the 9th International Coral Reef Symposium in Bali in 2000 and the ICRI meetings in New Caledonia in 2000, and the Philippines in 2001. These consultations resulted in the prioritisation of research themes, identification of the best scientists in the field to undertake this research, and the narrowing down of field sites in line with existing knowledge, research infrastructure, GEF investments and anticipated budget.

The Working Group Chairs, selected to lead the effort in the key thematic areas, are pre-eminent in their fields. They are highly respected scientists with international reputations. These chairs were then invited by the World Bank's team to form working groups based on the following criteria:

1. *That demonstrated scientific excellence and rigor be a defining quality of working group composition*
2. *That where possible, the working group include developing country scientists who clearly meet the first criterion in the field of investigation*
3. *That size of the working group not exceed a critical threshold beyond which it is difficult to act efficiently and with consensus*

4. *That the working group members be individuals who are willing to commit to an atmosphere of team work and coordinated investigations, and who are willing to share knowledge and approaches with others in developing capacity at every opportunity.*

Further communication of the concept and of the emerging working groups was made to the external scientific community during a number of workshops supported with Block B funds. These exemplified the consultation and learning exchanges that the TR Project espouses, and will continue to be a hallmark of the targeted research model through involvement of the Centers of Excellence (See Brief Section E.4.1). Examples of these include two workshops, which were held in:

- *Heron Island, Southern Great Barrier Reef, University of Queensland, 25 Feb – 18 March 2002, attended by 48 researchers and students,*
- *Puerto Morelos, Mexican Caribbean, Universidad Nacional Autónoma de México, 9-22 September 2002, attended by 25 researchers and students.*

At these meetings, Working Group members engaged with other senior researchers (invited as distinguished guests) to share their knowledge and exchange ideas with young doctoral and post-doctoral students from participating developing and developed countries. This has allowed researchers to collectively discuss, peer-review, design and implement research priorities jointly at two of the four COEs, while at the same time share information and results across a broad generational gradient (i.e. an apprenticeship model). At the end of these exchanges, reports have been generated that have resulted in furthering post-workshop application of the information. The TR workshop concept also serves as a good mechanism within each of the COEs for integrating science into management considerations by facilitating regional discussions and learning exchanges among scientist, managers, policy-makes, NGOs and public sectors.

The scientific members throughout the working groups are already well connected within their community of practice, and most, if not all of the WG members are also members of the International Society for Reef Studies (ISRS), and National Chapters of other scientific organizations. The ISRS hosts a quadrennial symposium on reef studies, and the next of these (the 10th ICRS) will take place in Okinawa, Japan in the summer of 2004. This project, and its working group representatives have already applied for –and have been accepted by the organizing committee of the ISRS—to host mini-symposia on this global project, and to seek ways in which the targeted research can be strengthened. In addition, the Targeted Research will support 2 ISRS research scholarships per year, to be awarded to outstanding scientists form developing countries who will carry out research hosted by the TR Project.

4. The different working groups work needs to be brought together under strong scientific leadership. From the present draft, it is not clear that the Synthesis Panel and its chair would be able to bring the multiple stresses and the work at the various sites together even with an external chair. The Working Groups state that the other working groups would provide the information, data or expertise, but again, from the description given, it is not clear how this is going to be done – what are the questions that would be addressed and how would the information be brought together. Thus, the role and the value added of the Synthesis Panel needs to be clarified, in addition to the synergies between the Panel and the Working Groups.

While we agree that strong scientific leadership is required to bring the working groups together in a coherent way, we take strong exception to the notion that such scientific leadership does not exist within the Project structure we have laid out. As noted before, the Chairs of the Working Groups and other members of the Synthesis Panel are world class scientists (see technical annexes posted on the website for lists of WG Chairs & members). Nevertheless, the Project Team welcomes recommendations from

the STAP of additional scientists whom they feel can contribute to, and provide periodic review of project results and its process.

The role of the Synthesis Panel as part of the larger Steering Committee, is crucial in reviewing scientific results, to provide a check and balance of priority hypotheses across the working groups, and relating them across the various disciplines to distil emerging trends, discriminate global from regional or local patterns of response and steer the research in ever more promising directions. The recognition of strong coordination has already been acknowledged, and this has been addressed in the revised section of the Brief on institutional arrangements. This has been informed by the results of a major study which was not complete at the time of the STAP review.

5. The project should state how it is building on existing information. It is not clear from the proposal on how the Project will interact and benefit from the existing GEF interventions which includes a coral reef management component. This should be further elaborated in the proposal. It is even more intriguing that there is little or no mention of how the project will build on what has already been done by institutions such as, ICRAN, ICRI, ICN, NOAA, others involved in the insular Caribbean and the Cooperative Research Centre for Reefs in Australia. These institutions and others can also become potential collaborators and their existing resources and networks can become part of information dissemination, e.g., as part of the learning exchanges process, the data generated can also be distributed via nodes such as SIDSNET, which already has nodes in the Caribbean and the Pacific.

The TR Project Team has consulted extensively with staff from the institutions and projects referenced above. ICRI has been briefed on the status of project development since its inception, at the first ITMEMS, and then regularly at ICRI Steering Committee (CPC) Meetings and Symposia. The project has the full endorsement of this group, and in fact, it was the result of a presentation to the ICRI CPC in Maputo in December of 2001 that the East African Node was added, at the insistence of delegates from the region, including scientists and managers. The existence of several GEF and other donor-supported projects supporting ecosystem-based coastal resources management in the MBRS region, active scientific research and a strong commitment of governments and NGOs to conserve the world's second longest barrier reef, was a major factor in the selection of this sub-region, as well as in identifying a demand and opportunity for channelling results. The MBRS Project, COREMAP, ICRAN and other global NGO marine conservation initiatives have repeatedly expressed their desire to use the research results generated from the TR Project to underpin and inform the interventions that are being promulgated under these management projects. Here, existing networks like ICRAN and SIDSnet can help to disseminate research information to the management community. In contrast to these management efforts, the primary objective of the TR is not to implement better management, or even good governance. It is, rather, to create a robust framework for good science (and extend that quality through targeted, scientific learning) which will lead to new tools, insights about how systems in different places respond to various kinds of stress and prospects for their recovery in a changing environment, how they are connected in space and time, and how this information can be related to allow managers and policymakers to anticipate with greater accuracy the impacts of their decisions and have a sounder basis on which to intervene. (See Brief Section C.3. Benefits & Target Population).

Institutions such as NOAA and a new Center for Coral Reefs and Climate Change at the University of Queensland are already enlisted as partners under the project and are providing significant co-financing (NOAA at approximately $10 million in direct and related co-financing; University of Queensland at approximately US $3 million in direct co-financing.) The TR is also building effectively on the investigations of its Working Group members, many of whom are engaged in cutting edge research in the field. For example, within the Connectivity WG, their proposed research will benefit from the following foundational work of its members:

1. *GP Jones has published **one of the only two studies** to empirically document retention of larval reef fish (Jones, G.P., Millicich, M.J., Emslie, M.J., Lunow, C. 1999. Self-recruitment in a coral reef fish population. **Nature**. 402, 802-804.) There are **zero comparable studies** on corals or other reef creatures.*
2. *RK Cowen is responsible for an important modelling contribution to connectivity thinking: Cowen, R.K., Lwiza, K.M.M., Sponaugle, S., Paris, C.B., Olson, D.B. 2001. Connectivity of marine populations: open or closed? **Science**. 287, 857-859.*
3. *S. Thorrold is one of the 2-3 leaders in use of otolith microchemistry to document sources of larval fish.*
4. *R. Steneck is a leading expert on the processes surrounding coral settlement and recruitment*
5. *M. Butler is a leading expert on spiny lobster settlement, recruitment and juvenile ecology in the Caribbean.*

6. There appears to be lack of consultation, needs analysis and engagement of the potential managers. We do not see evidence that the management action will result from the scientific findings. Is there evidence that the managers are looking for 'science-based' solutions? Have they been consulted (i.e. user needs assessment done) and if so what were the outcomes? Have the managers had information presented to them by individuals or institutions involved before and have the managers taken action? There is no clear mechanism presented on how the scientific information will result in management actions.
Please see the response to comment #3 above. The ability to link the scientific findings to management and facilitate its uptake is both a key objective and a major challenge of the Targeted Research Project. The Project team recognizes the strategic importance of promoting these linkages in: (i) the prioritization of research questions, (ii) formulation of hypotheses in ways that suggest management-relevant outcomes if the hypothesis is accepted or rejected, (iii) testing of research tools (such as remote sensing, fish larval dispersal markers, and field assays to diagnose stress in indicators species and diseases in corals), (iv) cost effective reef restoration techniques and (v) designing decision support tools to enhance management. All of these are core elements of the research. Managers were in fact consulted during project preparation (during the Block A and later in the Block B, although a formal assessment of managers' needs was not undertaken) in professional meetings and side events at international conferences dedicated to this purpose, through ICRI, ICRAN, and GEF project teams, with NGOs such as The Nature Conservancy and WWF¯all of whom have identified a demand for knowledge and products among their constituents of the kind the TR is being designed to generate. An example is the growing interest among MPA managers in the notion of connectivity within and between ecosystems, its importance to maintaining the integrity of marine ecosystems and their supply of goods and services (e.g., in the context of fisheries recruitment and recovery of damaged coral reefs), how to measure it in the areas they manage, and how to use this information to design effective and resilient networks of MPAs. Without the science to explore this properly, estimates of connectivity between reefs will continue to be based on flawed concepts of surface currents, passive transport, and dispersal potential for one or two species. The result will be a continuation of the trial and error approach to management—a costly approach given what is at stake for coral reefs and those who depend on them.

To help managers ask the right questions of scientists and to sharpen the focus of the TR on management issues of local importance as well as global interest, the Centers of Excellence will need to play a strong role in bridging these two communities. The COEs can facilitate a combination of adaptive management and applied science by maintaining a dialogue between local managers and scientists in the region who are engaged in the TR. Similarly, creating opportunities for periodic consultation and outreach to local communities and incorporation of traditional knowledge in the process of addressing unknowns will be a responsibility of the COEs. They will be represented on the Capacity Building Sub-Committee along with

other members of the Steering Committee, to help strengthen the linkages between science and management and ensure that local benefits are generated from the research undertaken. In a recent site visit to one of the proposed Centers of Excellence, the local representative immediately recognized the value of this approach. Upon learning of the plans for this proposal, he stated: "We need to stop shouting at one another based on emotion and rhetoric. We need answers from helpful, adaptive, science". NGO collaborators in the TR, such as TNC and their affiliates, also have a strategic role to play in ensuring that the research findings are interpreted for various stakeholders and channelled effectively to these groups. Through their "Toolkit for MPA Managers" which aims to include measures to assess coral bleaching and guidance on how to minimize MPA vulnerability, and to enhance recovery from these and other disturbance events (including pollution, disease and blast fishing) the TR Project will have a ready conduit for the uptake of relevant findings from the various working groups as they emerge.

7. Management implications/outcomes are weak in all the working groups and need to be strengthened.
*(Please see technical annexes, as well as a separate file on project website: http://www.gefcoral.org that discusses management implications.)*Linkages to other working groups are weak, including data/information and methodology transfer. Further information has to be presented to really demonstrate the mechanism for the transfer of the information to the managers and its subsequent use.
See discussion of CoE's role in information dissemination to managers; see Brief section E.4.1 and section D.5 regarding policy dialogue between Bank and Clients).
Section D, project rationale, does not mention the underlying causes. The management options should surely have to consider these before any "new" management strategies are put into place.
Please see the response to point 6 above. Examples of more specific management outcomes include the following (in this case, from the Connectivity Working Group):

a. *Development of novel chemical methods for tracing sources of larval fish*
b. *Development of novel genetic methods for tracing sources of larval fish and corals*
c. *Use of data on recruitment variation in a novel way to test the realism and precision of models of dispersal of fish and lobster*
d. *Use these novel approaches to provide estimates of connectivity in Mesoamerica for a) one breeding population of Nassau grouper, b) one or two representative reef fish species, c) one or two species of coral, and d) spiny lobster.*
e. *Application of these same methods (modified as necessary depending on discoveries in Mesoamerica) to fish populations in the Philippines and coral and fish populations in Palau. (Thus capturing instances of connectivity in a continental Caribbean, a continental Pacific, and a mid-Pacific location.)*
f. *Educating graduate students in each region in the course of carrying out the research.*
g. *Engaging the management and NGO communities as participants in the research, as a deliberate way to enhance understanding of the problem, and its importance for management.*
h. *Development, through a series of workshops, a clear appreciation in each local region of how the data obtained can be used to make better management decisions than would otherwise be possible.*

8. We encourage the project to incorporate the *active* involvement of local communities from the beginning. The approach taken at each of the sites appears to be very top down. We have seen little or no mention of the local communities that do manage and rely on many of the coral reefs of the world. In some cases, we hope that they have people who have already been doing work on the ground as otherwise it is going to be very hard for the scientists and managers to walk in and do the work (e.g. in Papua New

Guinea). Therefore, an initial stakeholder analysis would help in identifying and engaging the local communities.

The STAP review raises a valid point and one the Project Team has been giving more thought to as the role of the COEs as interlocutors with local stakeholders and as centers for outreach and capacity building has become better defined. The centers in Puerto Morelos, Bolinao, Zanzibar and The Great Barrier Reef will not only serve as regional resource centers, but as focal points for engagement of the local community in research that will have an impact on their livelihoods and security. Rapid ecological appraisal promoted by NGOs such as TNC and partners for use by local communities, could provide a modus operandi as well for local community involvement in some aspects of the research. This would also be an opportunity for researchers to solicit local and traditional knowledge to help frame research questions in ways that are more meaningful to local groups. Thus, the findings could also be more readily interpreted and disseminated.

A workshop in Mexico being planned for early in Year by the Connectivity WG will bring together individuals from management agencies already committed to the Synoptic Monitoring Program (SMP) designed to monitor the health of the Mesoamerican Barrier Reef, under the MBRS project, to teach them how to monitor recruitment of fish, corals and lobster, and encourage the inclusion of these measurements within their SMP activities, while also teaching them how recruitment information is needed for study of connectivity, and how it can be used to inform management actions. This may be the first of an on-going dialogue with the management community that will build their capacity, while assisting in the data collection required for aspects of the connectivity project. This and other vehicles for active participation of local communities and managers will be explored during the early stages of project implementation. (See Brief Section E.4.1)

9. We are concerned about the participation of developing country scientists and the funds that will be allocated to them. It would be helpful to indicate what is the ratio of experts from developing countries participating in the research, and what is the proportion of funds being allocated to developing countries.

*From the outset it has been a fundamental principle of the TR Project that support for developing country participation in the project would be a high priority. Working Groups agreed that support for students and post-docs would be **earmarked for individuals from the regions** in which they would be working, (i.e. Mesoamerica, Eastern Africa, South East Asia and Melanesia), not from developed countries, and that, wherever possible, these students would be **enrolled in institutions in the region**, even if they were seconded to developed country labs for portions of their education. The fact that Working Group membership is skewed toward developed country representation is a simple reflection of the current skills distribution in the areas of investigation targeted by the project (see complete list of Working Group members on project website: http://www.gefcoral.org). In spite of this and the limitations imposed by the budget on the total number of members in each group, the Working Group Chairs have done an excellent job of having developing country scientists represented within their groups. The current percentage of developing country scientists involved in the WGs are as follows:*

Bleaching and Local Ecological Responses WG:	*30%*
Connectivity and Large-scale Ecological Processes WG:	*20%*
Disease WG:	*37%*
Restoration and Remediation WG:	*27%*
Remote Sensing WG:	*25%*

Modelling and Decision Support WG: 43%

We fully expect to see these percentages increase as the project moves forward. As a case in point, with respect to the Connectivity Working Group, faculty from CINVESTAV-Merida, and at ECOSUR-Chetumal (Mexico) will be added to participation in the research, as well as additional faculty from the node at UNAM.

10. There appears to be a lack of post-intervention follow-up and needs to be stated clearly. In terms of GEF global environment impacts, it is important to identify follow-up strategies. It seems to be missing entirely in the documentation. Further clarification is needed on what entities would follow up after the interventions? How would the follow-up occur?
The TR project is being designed as a 15 year program, thus follow up after the initial five year phase is being anticipated in a second and third phase. This will depend on the achievement of outputs and progress against performance indicators in the initial phase. GEF funds would represent a substantially smaller percentage of the overall project cost, as new partners are recruited and the research infrastructure (human and physical) becomes mainstreamed into institutions supported by the TR. (See sections on sustainability and replication in the Executive Summary and in Section F of the Project Brief).

11. Some of the assumptions being made need clarification and testing, (e.g. disease and the interaction with water quality is too simplified and generalised) and the appropriate Working Groups need to add that this will be tested. We feel that the project should point out the challenges and also the assumptions that apply to the replicability and transferability of the results.
The Working Groups are keenly aware of the assumptions involved in this adaptive research model, and of the associated problems and trade-offs. The tables that accompany each of the technical annexes have attempted to organize the information for each of the priority hypotheses so that the latter could be evaluated along with the assumptions, and then ranked for each Working Group. The Scientific Committee would review these with the help of the Synthesis Committee to determine which ones should be approved and how they should be ranked in order of importance. Replicability of investigations (and their inherent assumptions) is dependent upon their place within the investigative hierarchy and whether the results should be interpreted (i.e. molecular or physiological responses to stress) globally or in a more local context, if they prove to vary considerably over space (e.g. different ecological responses of populations in different regions). Communications between the Working Groups and their chairs, and the Synthesis Panel's oversight and synthesis of the findings will help determine the transferability of the results.

12. The summary of the proposed work by some of the Working Groups (see below) is excellent, but some others need to be strengthened both in terms of the methodology and perhaps the experts involved. In particular we would like to highlight our concerns about Modelling and Decision Support Working Group and within that "Field validation". Field validation is a critical aspect and needs to be considered in more detail than in the cursory manner presented here with (both within the main project proposal and in the Technical Annex 1). There is no indication as to how field validation will be undertaken, and no consideration of temporal and spatial scales etc.
We accept this comment, and are working to see that methods and approaches are standardized and coordinated between working groups. As a case in point, an upcoming joint meeting in the Philippines in October--as part of the on-going Block B phase--will examine the issue of recruitment on coral reefs, and the ways and means in which working groups can coordinate their methods--to ensure that consideration

is being given to variation in temporal and spatial scales, that common assumptions are carefully examined, and that there will be cooperation to help validate proposed models. As for additional experts, we feel confident that the Working Group chairs have carefully considered the caliber of researchers involved. However, we welcome any suggestions of the STAP to forward to the Chairs for consideration.

More specific comments on the Working Groups

Our comments are based on the Annexes in the main document but we have also checked in the six Scientific Annexes provided. The quality of the documentations in these annexes seems to vary considerably. Again a strong scientific leadership for the whole project could help overcome this.

We believe that this leadership exists within the capability of the Synthesis Panel membership, and this will also be addressed in considering the role of the coordinators within the Project Executing Agency.

Some comments across the working groups are:

a) Scaling issues: Some of the information (e.g. IPCC scenarios) are available mostly at the global level, and yet the coral abundance, reef biodiversity etc is a t local and at best regional level. How would these be incorporated into the models?

Reconciling the variations in scale between organisms, communities, their habitats and ecosystems is a fundamental challenge that is a foundation of this targeted research. These are questions that have been explored in the literature since the mid-1990s, and are being examined as part of this project. One such approach looks to rule-based modelling that explores differences in scales as a consequence of the agents that run independently and then interact within the system (http://www.ncoremiami.org/WaterModel.htm). While the appropriate modelling approaches are being considered, the working groups have prioritized many of the investigations with differences of scale in mind. This is clear within technical annex #1, where the working group has prioritized its investigations to deal with the molecular mechanisms of coral reef bleaching as the pre-requisite to ecological studies that will examine its cause and effect under various forms of stress.

b) Some of the modelling work mentioned in various work in the appendix is hard to do on land let alone an "open" system as that of coral reefs. We are not convinced that enough thought has been given to this critical section in all the working groups.

Comment noted. There is value in each of the working groups developing need-specific models in conducting (or evaluating) targeted research within a given working group's activities that may or may not contribute to the larger issue of decision support and field validation for a larger expert system. This is somewhat of a separate issue from the design and development of a larger decision support tool. In addition to any MDS tool developed by the MDSWG, the Synthesis Panel will have a role in decision support for the overall project. However, we accept the comment that discussion of specific modelling within each of the working groups, and their relationships and inputs to a decision support model can be clarified within the project Brief (see Brief section E.3).

c) Only $3.0 million are allocated to "linking scientific knowledge to management", the same amount that is allocated to project administration. If the former is an important goal of the project, is this level of funding proportionately adequate? Perhaps the team might wish to revisit this funding allocation.

We appreciate the need to allocate resources in a way that is consistent with our assessment of the importance of the various components. While $11 Million in GEF ($20 Million overall) may seem like a lot to allocate to Targeted Research, the scope of this effort is quite large relative to the available resource envelope. Because of the Project's complexity, Project administration and management will be crucial to ensuring that technical components are well executed. The challenge will be to increase the

envelope for these technical elements, through additional co-financing, not to reduce the overall allocation for administration. The bulk of project administrative costs will be covered through co-financing.

Specific comments on each of the working groups proposed work:

1. Bleaching Working Group: has some weaknesses. Some parts of the summary of the proposed work are excellent, however, other portions of the summary are less thorough, and give the impression that little or no work has been done in the three activities listed in the first paragraph. We can only assume that since some of the processes involved, eg. changes in physiology to individuals reef systems, globe, are long-term that data needed on this would be somehow (through individuals and institutions involved?) be incorporated in the project.

This comment appears to be restricted to the summary presented within the Draft Brief, as opposed to the more detailed presentation within the technical annex for this working group, which is much more comprehensive in the description of priorities and work programs. The above comments will be taken into consideration during final approval of the document; however, it should be noted that the Working Group has made significant progress in prioritising the relevant hypotheses for each of the three activities, although it cannot be expected that these would all be addressed in comprehensive detail in the pilot work during the Block B phase. This Working Group has made significant progress in understanding the physiology to date, but as stated in the response in a), above, it has prioritized its investigations to deal with the molecular mechanisms of coral reef bleaching first, as the pre-requisite to ecological studies that will examine its cause and effect under various forms of stress as the project gets underway.

2. Diseases Working Group: overall good.

3. Connectivity – various issues need to be improved, such as:

The connectivity work in Mesoamerica has had a healthy head-start due to prior research there by a significant percentage of working group members (Sale, Cowen, Steneck and Butler, and the inclusion of experts like Thorrold, Planes and Jones). Some parts of the research are straightforward and will work; others are more risky. For example, the studies of coral larval dispersal may hit difficulties not yet foreseen. The modelling goal using fish recruitment and lobster recruitment as data to test the accuracy of dispersal models should work, and if we can build good dispersal models, these can then derive connectivity estimates. Otolith chemistry will either be superb or disappointing, but if the latter, we will know that investing in it is not warranted. The same goes for assignment tests using genetic data. The proposal is structured on the understanding that there will be mid-course corrections, as is the case in any research project worth funding. The track-records of the working group members as leaders within their fields should instil more confidence than is apparent by the STAP comments.

a. It is not clear as to what techniques will have to be developed and which ones will be further expanded.

There is considerable technique development in: otolith chemistry - finding ways to label otoliths and, perhaps, using otolith cores as signals of natal locations, coral genetics – finding markers that show relationships in time and space, coral ecology – developing immunogenetic probes to identify planula larvae, physical oceanography – using neutral density beads to mimic dispersing eggs or planulae. Most of the work, however, uses known methodology in novel ways or in novel combinations, such as a) the suite of activities planned at a spawning aggregation to yield data on larval dispersal and subsequent locations of the aggregated adults, b) using otolith cores as signals for natal locations for fish recruiting

across a region, c) using genetic assignment tests to assign larval fish or coral recruits to specific source populations, d) using data on recruitment patterns of fish or lobster as a way of testing the accuracy/realism of models of dispersal (much modelling seems to be done without any effort to see if the model is realistic, and dispersal is a complicated process). In many instances it is the particular combination of approaches, frequently from different disciplines, that is novel, and potentially able to actually measure connectivity.

b. How long would it take to do develop the tools to identify and monitor stress and would these techniques be easily and quickly transferable to the other regions?
Connectivity is an intrinsic property of open ecological systems. It occurs in the presence and in the absence of stresses on those systems (it may or may not be modified by the stress). We need to learn how to measure it, because knowledge of connectivity is essential if we are to manage these systems in any spatially-explicit way – such as through creation of networks of no-take zones.

c. Is any of the information transferable to other regions and coral reefs with different history, biodiversity and set of stresses?
Yes, all of it. But with the usual caveat: one measurement yields one result – it gives us a clue about scale, but we won't appreciate the variance within that scale of response until more results are obtained. If we discover that larval Nassau grouper from the Glovers Reef spawning aggregation site, spawned in February 2006 end up on reefs stretching from Turneffe to northern Belize, and on Chinchorro, Cozumel, and Key West, that tells us a lot about dispersal of that species that year in that site. We will not even know if that was an exceptional year (or an exceptional site), but we will know a lot more about it than we do now. At present we know a) that a proportion (small or large – not really sure) of one small damselfish, spawned at Lizard Island, settled to sites at Lizard Island one year (retained on scale of 5km), and that larvae of one small wrasse recruiting to sites on St. Croix USVI were 'predominantly' produced on that island rather than elsewhere in the Caribbean (retained on scale of 20-50km).

d. Are the researchers concentrating on "keystone species" so they may obtain a good understanding of the critical processes?
No. Reasons for species selection vary: Nassau grouper – typical of aggregating spawners, has functioning site near research facility at Glover's Reef, there is on-going research on this population, it is a charismatic species, and Belize has recently protected all spawning aggregation sites. Therefore, this is a good opportunity to give them data about how one site functions. Bicolor damselfish – typical non-aggregating spawner, easily recognized so field collections can be done by local stakeholders, common and widely distributed. Spiny lobster – economically most valuable fishery species in Caribbean, has very long larval life relative to fish being used, or to corals. Montastrea –largest reef-building genus within the Caribbean; existing genetic and juvenile work in progress, widely distributed, abundant. We are focusing heavily on fish because the chance of success seems greater with them (more effort has already been expended to measure fish connectivity than is case for other reef species), and because they are economically important (to both fisheries and tourism).

e. Is there a logic for choosing to concentrate on lobsters, groupers and snappers?
See above.

4. Restoration Working Group: well presented summary of the intended work, although again it would have been useful to say if pilot or other work suggests that the experimental work being suggested can be done over the spatio-temporal scale of the project.
5. Remote sensing Working Group: this seems to promise a great deal and we are not sure if it can deliver. Some of the techniques are a challenge in land-based systems and we are not convinced that these

can be done in the coral reef systems. Further information on how the project team plans to address this would be useful.

The reviewers' point out that some of the objectives for this WG are challenging and difficult to accomplish on land. They request clarification but do not specify which issues they consider to be particularly difficult. Therefore, this response focuses on those generic remote sensing questions which are applicable to terrestrial systems.

1. Firstly, it is important to point out that the RSWG has met on four occasions and has rigorously reviewed the feasibility of all projects under consideration. Some of these were considered too challenging given the immaturity of the science and limited resources available. These issues will be revisited before the second phase of the study.

2. One of the reasons the RSWG is able to propose a great deal of research activity is that the RSWG have acquired considerable co-funding (note that NOAA is a significant co-funder of our effort as per STAP comment #5 above).

3. Spectral unmixing: The process of spectral unmixing is challenging in any environment and especially so through an aquatic medium. There are two key problems:

a) Determining the depth of the overlying water column without field data. The RSWG have already solved this problem using mathematics and optimisation routines (Hedley & Mumby 2003). Essentially, if the spectral imagery has more spectral bands than there are substratum classes on the seabed, then a series of simultaneous equations can be solved to estimate depth. Specifically, the method inserts a potential depth value and determines whether the equations are compatible after Gaussian elimination. The process is repeated with varying depth estimates until equations become compatible, giving the correct estimate of depth. The required inputs are (i) the diffuse attenuation coefficient of each spectral band and (ii) the end member spectra of individual substratum types or a combination thereof. Both can be determined from the imagery with minimal field work (approx. one day of ground survey).

b) Applying a linear unmixing method. Once the influence of depth is removed by adjusting reflectance values to uniform depth (e.g. the surface), an unmixing algorithm must be applied. Most methods make the simplifying assumption that spectra mix in a linear relationship to the composition of substrata in the pixel. The RSWG undertook pilot work during the Block B phase and tested whether a linear unmixing method will represent coral and algal mixtures. Experiments were carried out at Heron Island (Australia) and Palau. Our results show that linear mixture models are a fair representation of coral/algal mixes with accuracies upward of 70% (considered high for such analyses in terrestrial systems). The paper is accepted for publication in the journal Coral Reefs (Hedley et al. 2003). The RSWG aims to improve on these accuracies by developing non-linear mixture models, better able to deal with the irregular shapes of corals. To do this, the WG members are developing a new form of radiative transfer modelling that uses radiosity methods. Radiosity methods were developed by the computer graphics industry to give stunningly realistic representations of sunlight in animations (e.g. the movie, "Shrek"). The RSWG is developing these methods further to resolve how light interacts with corals and algae. The net outcome of this research is that managers will be able to monitor the health (coral and algal cover) of their reefs using airborne remote sensing and future satellite sensors which will have an adequate number of spectral bands. This provides greater spatial representation of the state of reefs and releases staff from the extremely time-consuming process of monitoring reefs in situ.

4. The detection of change in reef systems

Change detection is a major area of remote sensing research both in terrestrial and aquatic systems. The RSWG believe that we are making significant progress in developing promising new methods and most

importantly, converting the expression of remote sensing science into that used by coral reef managers. This latter objective is vital if managers are to make greater use of remote sensing (and in so doing, undertake management more cost-effectively). For example, the standard presentation of accuracy for a habitat map involves confusion matrices. However, managers are concerned with achieving a certain statistical power in detecting say a 10% change in coral cover over the course of a year using Analysis of Variance. We are bridging this gulf in statistical methods by undertaking ANOVA power-analysis with remotely sensed data (e.g. Mumby et al. 2001).

Many of the methods the RSWG is developing for change detection rely on changes in the texture and local autocorrelation in reflectance. These methods have already been developed (LeDrew et al. 2000) and there is compelling evidence that the texture varies between many reef habitats (Mumby & Edwards 2002). To investigate these questions further, the RSWG are using an innovative approach in which several images are acquired in rapid succession (e.g. 2 months). Atmospheric conditions differ amongst images just as they would if using a longer time series. However, if the RSWG makes the reasonable assumption that the status of reefs has not changed between images, then texture of individual reef habitats can be compared from image to image. Indeed, with the field surveys planned at each study site, the RSWG will be able to determine how depth, water turbidity, and biogeographic regions influence the separability of reef habitats by each method.

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Mumby PJ, Edwards AJ (2002) Mapping marine environments with IKONOS imagery: enhanced spatial resolution does deliver greater thematic accuracy. Remote Sensing of Environment 82: 248-257

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6. Modelling and Decision support Working Group: this is the weakest WG in terms of the information presented. We are not sure if there is sufficient data available to develop an expert system. What are some of the challenges and can they be overcome? How will field validation be done? This is not trivial and should be clarified (see point 13 above). 12 major sets of models are being proposed and it is not clear how they will be integrated; there will be challenges in terms of information available and their spatio-temporal scales and yet this does not come across in the summary presented. We are not convinced that the research will lead to definite management implications

Comments noted, and will be taken into consideration.

The concern about whether or not our work will improve management also indicates that we have not gotten a simple point across: A well-built GIS of a reef and adjacent land almost always improves management decision-making. Where it does not, it is usually because it was built and then never used effectively by managers and policy-makers, or there is a failure in political will. Any good GIS of such a system combined with appropriate documentation also establishes a detailed case history of trials, successes and failures in managing a coral reef. There is no more useful guidance for improving coral reef management globally than providing access to well understood case histories. This is the reason we

are using such an approach in working with the initially limited number of sites within the four regions (and Centers of Excellence), and in coordinating the work of the various working groups. The aim of the MDS is to build good, easily-used GIS systems, and then to carefully add to their capabilities by augmenting them with other decision support capabilities (including simulation), filtered via validation. As long as we are improving GIS for reef management purposes, then we are extremely likely to be improving reef management.

Some minor points on the main project proposal

- Section B, page 2 onwards. It would be worth mentioning climate variability as well as climate change is being considered; is "unprecedented" bleaching and not "unprecedented mortality" on page 3. The section does need to mention the temporal aspects and the potential time lags that might be of relevance to the coral reef systems
  Comments noted.
- Would the TR really lead to a "new generation of trained scientists" (page 20) in 5 years?
  The team believes that the case has been clearly made within the Brief that this is not the intent. A "new generation of trained scientists" is intended to take place over the life of the three phases (15 years) of the project.