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Coral Bleaching: Causes, Consequences and Response

Selected Papers Presented at the
9th International Coral Reef Symposium
October 2000

CORAL BLEACHING:
CAUSES, CONSEQUENCES AND RESPONSE

Selected Papers presented at the 9th International Coral Reef Symposium on "Coral Bleaching: Assessing and Linking Ecological and Socioeconomic Impacts, Future Trends and Mitigation Planning"

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Many of these individuals worked extensively outside the mini-symposium to bring attention to both the implications of mass coral bleaching and the options of response available to managers, policymakers and researchers. Their thoughtful work has reemphasized the case for strong international commitments to a coordinated response to mass coral bleaching.

We especially appreciate that the session and this publication were made possible through the financial support of the East Asia Pacific Environmental Initiative, a joint initiative of the U.S. State Department and the U.S. Agency for International Development (USAID). Many thanks to Tim Resch of USAID and U.S. Department of State, who oversaw this process and provided advice and encouragement.

We would also like to thank Brian Crawford and Lynne Zeitlin Hale of the Coastal Resources Center at the University of Rhode Island, who conceived the idea of bringing the mini-symposium papers together into a volume. Tom Bayer and Chip Young, also from the Coastal Resources Center, were instrumental in expeditiously transforming the manuscript into its final form.

Without the participation of all these individuals and institutions, the field experience and lessons learned about coral bleaching and management alternatives, which are the basis of this compendium, would not have been possible.

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PREFACE

Coral reefs have long fascinated human beings with their myriad of life forms and colors. Coral reefs are among the most biologically diverse ecosystems on the earth, but are degrading at an alarming rate in all tropical oceans. Throughout the Indo-Pacific, only a small fraction of reefs are considered to still be in excellent condition. Many reefs are seriously degraded, particularly in the Philippines and Indonesia.

In 1998, the negative impacts of destructive fishing and over-exploitation of the reef resources in the East Asia-Pacific region were compounded by mass coral bleaching and consequent coral mortality. Coral bleaching events are increasing in frequency, extent and severity. These large-scale bleaching events are linked to global climate change and are expected to be a recurring problem. Because most island and coastal populations in the East Asia-Pacific region depend on coral reefs for nutrition, fisheries and tourist income, as well as coastal protection, mass coral bleaching and mortality create an environmental and socioeconomic crisis that requires development of a focused, coordinated response. This response must be based not only on an understanding of the causes of coral bleaching and the interaction of bleaching with other coral reef stressors, but also in recognition of initiatives already ongoing which seek to understand and mitigate the long-term impacts on coral reefs.

In November 1998, the International Coral Reef Initiative issued a "Statement on Coral Bleaching," anticipating negative consequences to tourism, fishing, coastal protection and other coral reef services. The Statement calls for interdisciplinary research to evaluate the immediate and ultimate causes of coral bleaching, and the effect of coral bleaching on the ecosystem. In 1999, a commitment was made by U.S. Agency for International Development and the U.S. Department of State, through the East Asia and Pacific Environmental Initiative (EAPEI), to research and address the socioeconomic impacts resulting from coral bleaching and to bring this information to appropriate international forums. These goals were realized in part through a special session at the 9th International Coral Reef Symposium in Bali, Indonesia, supported by EAPEI funding.

This compendium captures the symposium's special session results. It brings together the experience in the science and management of coral reefs under conditions of climate change, emphasizing socioeconomic aspects of coral bleaching. We sincerely hope that this compendium will be both informative and interesting to practitioners, decisionmakers and researchers. We hope it focuses attention on the need for effective and innovative approaches to management of coral reefs. With awareness, knowledge and action, the viability of coral reefs will be assured.

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ECOLOGICAL AND SOCIOECONOMIC IMPACTS OF CORAL BLEACHING: A STRATEGIC APPROACH TO MANAGEMENT, POLICY AND RESEARCH RESPONSES

By Heidi Z. Schuttenberg[1] and David Obura[2]

The biological impacts brought about by the 1997-98 mass coral bleaching resulted in a dark host of management, policy and research issues. Many sessions at the 9th International Coral Reef Symposium attempted to decipher the ecological repercussions of the 1997-98 event and to forecast this understanding into the future. Among these, the mini-symposium reproduced in this volume was unique in its interdisciplinary breadth. A tone of urgent optimism evolved during this session as insights from individual papers appeared to collectively suggest a possible strategy for response beyond, as one practitioner lamented, resorting to anti-depressants.

This paper attempts to summarize the collective findings of the session in support of its own conclusion: mass bleaching is one of many stressors cumulatively affecting coral reef communities, and there are meaningful management, policy and research responses to mass bleaching events that can be identified and pursued at multiple scales, from local to global.

The significance of this conclusion is threefold. First, it demands that the coastal management community not be deterred by the abstraction of global climate change, the root cause of mass coral bleaching, and one must believe that developing a sensitive understanding of the mechanisms and consequences of mass bleaching will expose reasonable responses. Answers are likely to be found through better understanding of key ecological and socioeconomic issues. For example, what opportunities for response can be discerned from the variable resilience of individual coral species and communities observed during the 1997-98 bleaching event? Similarly, what mitigation options become apparent when considering the specific socioeconomic consequences of coral bleaching on fisheries and tourism?

Second, in highlighting that bleaching is one of many stressors with the potential to impact reef quality, coastal managers simultaneously recognize that efforts to address bleaching are benefiting from a body of experience in developing effective approaches to coral reef management. This narrows the issue to one of implementing what is already known while concurrently sharpening tools that are bleaching-specific.

Third, although important questions about mass coral bleaching remain, the consensus of the session confirmed that there are meaningful actions which can and should be implemented even before the full implications of mass bleaching are fully understood. Such implications will better position future response efforts and is consistent with international recognition of the precautionary principle.

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To suggest that a reasonable response to mass bleaching can be found within the nuances of vulnerability and survival implies an intimidating complexity. While the science behind a strategic approach to bleaching may be involved, the underlying principle recommended here is very simple: create situations that maximize the potential for resilience and recovery. The building blocks to meet this aim are familiar and retooled to recognize the unique challenges and consequences of bleaching. They include integrated coastal management (ICM), marine protected areas (MPAs), public education and capacity building. These responses must be supported by research that is directed toward management questions and policies committed to allocating the necessary financial and human resources for effective implementation. Ultimately, the strategic response to coral bleaching should include policies to address global warming through the reduction of greenhouse gases. Public education on the causes of coral bleaching will continue to create a constituency for the eventual actions required to address climate change.

There is currently not enough information to fully understand the severity of future bleaching events, nor the extent to which recommended responses will counteract the impacts to both reef and human communities. The impacts of the 1997-98 mass bleaching event justify serious concern. However, these impacts do not indicate hopelessness or justify inaction with regard to coral reef management in general, or coral bleaching in particular. Implementing current measures will empower those involved in combating threats to coral reefs to better respond in the future as it becomes clear whether one is dealing with optimistic or pessimistic scenarios for the severity and extent of mass bleaching. In support of such action, this summary reviews the linkages, impacts, and the agenda for action presented during the session. These ideas are more fully explored in the papers comprising this compendium.

Ecological Consequences

It is well established in the coral reef scientific community that rising sea surface temperature, driven by global climate change, is the major factor in mass coral bleaching events around the world (Salm, et al., Gomez, et al., this volume). Many other factors are known to cause coral bleaching on local scales, such as temperature highs and lows, excess solar radiation, fluxes of nutrients and chemicals, physical obstruction such as by sedimentation, and disease. However, only climate-related anomalies, usually associated with extremes of the El Niño Southern Oscillation (ENSO), have been attributed to the massive bleaching events first noted in the early 1980s (Wilkinson, 2000). Broader recognition in global scientific and policy communities of the link between climate change and mass coral bleaching is occurring, illustrated by policy statements such as that released on bleaching by the International Society for Reef Studies, and in the Convention on Biological Diversity.

Gomez et al. (this volume) discuss the exact mechanisms behind coral bleaching which may include: a loss of symbiotic algae (known as zooxanthellae); the degradation of cells housing the zooxanthellae; or, a loss of photosynthetic pigments. Loss of the zooxanthellae causes the coral to appear white as the limestone skeleton becomes visible through the transparent tissues of the polyps. The physiological consequences of bleaching to the coral can be severe and lead to mortality, with subsequent ecological consequences to the coral reef ecosystem due to the key role of corals in maintaining ecosystem structure and function. Basic research on the physiology, ecology, molecular biology and taxonomy of the coral-zooxanthella symbiosis is advancing rapidly as the massive impacts of coral bleaching are becoming clear and the scientific community attempts to grapple with this emerging threat to the world's coral reefs. However there remains some disparity between scientific research and the key questions of coral reef management. Gomez et al. highlights some areas in which basic research is needed, as well as recommendations for management action where research may be lacking.

The papers by Gomez and by Salm, in this volume, identify two key concepts that may have the greatest bearing on the survival of coral reefs, and on our ability to actively protect and foster the growth and recovery of reefs in the future. The first of these is adaptation, which the Gomez paper describes as where "organisms may either acclimate by modifying components of their physiological processes to perform better … or they may adapt via selection of individuals within the population that are more able to cope…" The locus of adaptation is at the level of the genetic individual (this is complicated by the presence of both coral and zooxanthellae genomes in the symbiosis), and is influenced by factors acting from the micro-site to the global scale. The observation that individuals of the same species may have markedly different bleaching responses to the same temperature regime is well documented, and adaptation by selection of resistant coral-zooxanthellae symbionts is an important question. The second key concept is that of resilience, particularly at the ecological scale. The paper by Salm notes a number of conditions that apparently promote survival of corals on some reefs, or in certain reef assemblages, where adjacent reefs suffer high mortality. The resilience of a reef to bleaching may also be affected by a host of other conditions that include its history of disturbance, severity and frequency of stresses, and recruitment patterns.

With regard to adaptation and resilience, science is still rudimentary with few clear suggestions for management interventions. Nevertheless, whatever the details of the particular situation, the existence of corals and reefs that are apparently resistant to bleaching suggests principles for the selection and design of MPAs in order to maximize reef protection. The paper by Salm notes that appropriate selection and design of MPAs acts on the precautionary principle whereby bleaching-resilient reefs can be protected while science attempts to understand why they are resilient. This strategy should help to preserve genetic and biological diversity, and provide source populations of corals and other organisms for reefs affected by bleaching. Essentially, management actions must be based on precautionary principles, pending improved understanding that early protective action will provide.

Another consideration of the ecological consequences of mass coral bleaching, is the extent to which direct action can rehabilitate and restore degraded reefs. A number of rehabilitative measures have been developed, including coral seeding and transplantation; however, the limited scale to which these can be applied, and the financial and technical realities of implementation in tropical developing countries undermine their widespread application. Research on innovative methods for facilitating recovery, perhaps through addressing the adaptation and resilience issues mentioned above, may hold more promise than the current focus on direct restoration.

Socioeconomic Consequences

The socioeconomic impacts of mass coral bleaching are theoretically known, based on the observed consequences from other causes of reef degradation. Bleaching can affect tourism and fisheries in the short term, with additional losses to coastal protection and other "services" over time (Wilkinson et al., 1999). Studies undertaken in response to the 1997-98 bleaching event provide the first empirical documentation and estimates of such impacts, allowing for refined understanding and better planning of effective responses. Some of the studies presented in this compendium emphasize the potential for well-implemented responses to reduce socioeconomic losses in coastal communities. If response measures can be effective in promoting coral recovery, then the ability to mitigate potential socioeconomic impacts is increased.

Fisheries

The dependence of subsistence fishers on reef-dependent fisheries throughout tropical developing nations emphasizes the potential for serious socioeconomic consequences to result from mass coral bleaching. The papers by Cesar, and by Westmacott in this volume highlight the vulnerability of these communities, given the few alternative livelihoods available in many instances, notably for island communities. They consider the effects of the mass coral bleaching on fishing communities in Bolinao, Pangasinan, Philippines and in the Indian Ocean region, and point out that impacts from the 1997-98 bleaching event are subtle if observable at all.

Expected impacts are deduced from fisheries ecology and touched upon by Cesar, et al. (more detail is given in Westmacott, 2000). Essentially, the composition and health of coral reef ecosystems are important factors in determining the structure of reef-dependent fisheries through the food and habitat "services" reefs provide. Temperature-induced bleaching that affects the condition and diversity of coral reef ecosystems is expected to simultaneously affect reef fish populations by reducing abundance and changing composition and distribution. Population reductions are predicted for reef-resident fish, large pelagic species that feed on reef fish, and small pelagic species that inhabit reefs for part of their life cycle. Changes in fish abundance may vary by species, shifting the composition of reef fish populations toward herbivores. As the Westmacott paper indicates, such a shift could negatively impact fisheries, as herbivores are lower in value than other species.

Both the Westmacott and Cesar papers describe minor increases in herbivores as expected, but it is not possible to show the causality between coral bleaching and these observations. One reason for this uncertainty, as well as the lack of other observable impacts, may be that coral bleaching is one of many stresses cumulatively impacting reef ecosystems. Cesar, et al. note that when bleaching is superimposed on reefs that are already over-fished, reductions in overall reef fish populations will not be observable since herbivores dominated the fishery prior to the bleaching event. The Cesar paper further suggests that fishers changing their fishing habits and patterns may mask impacts occurring on small spatial or temporal scales. Westmacott, et al. propose that impacts to fisheries may become more pronounced over time once the structure of bleached reefs is further eroded.

Tourism

In the short term, the most dramatic socioeconomic impacts resulting from the 1997-98 mass bleaching event are the estimated losses to reef-dependent tourism. These losses are described in three of this volume's presentations. These papers focus on the diving destinations of Palau (Graham), El Nido, Palawan, Philippines (Cesar) and the Indian Ocean region (Westmacott). Some of the major findings include:

- US$3 – 4.6 million direct losses in Zanzibar, Tanzania and US$13 – 20 million in Mombasa, Kenya with total welfare losses of US$1.88 – 2.82 million and 10.06 – 15.09 million, respectively.
- US$3 million and US$.02 million direct financial losses with corresponding losses in total welfare of US$ 19 million and 2.2 million in the Maldives and Sri Lanka respectively.
- US$15 million loss in net revenue to the Philippine economy with corresponding losses in tourist welfare of US$14.6 million.
- Losses to the diving industry in Palau at as much as 10 percent of the diving industry's producer surplus and 20 percent of the visiting divers' consumer surplus, or approximately $350,000 each year following the bleaching event.

The manifestation of these losses is multi-dimensional and include a) impacts on tourist destination choice, which results in lost visitation and therefore a total loss of tourism revenue; b) impacts on choice of activities pursued, which may reduce coral reef-related revenue; and, c) reductions in tourist satisfaction of the diving experience as a result of degraded reef conditions. One implication is that tourism will be impacted to the extent a destination can maintain its status and reputation even in the face of reef degradation, by promoting other unrelated attractions. It is further possible that impacts to the diving industry can be mitigated to the extent divers' attention can be diverted to other focal points such as wrecks or by observing coral bleaching as an attraction. Such diversification may be difficult. While resorts in El Nido, the Philippines have been shifting market segments from divers to honeymooners in response to reef degradation, there is still an estimated annual loss of US$1.5 million.

Understanding the influence reef degradation has on diver decisionmaking is tricky, but important to predicting the economic impact of future bleaching events. It is related first to tourist knowledge of the marine environment and coral bleaching and secondly to the influence this understanding wields over consumer choice and satisfaction. Each of the session papers reports relatively low tourist awareness of coral bleaching (typically 25-50 percent of the respondents surveyed[3]). Those tourists whom were aware of coral bleaching, relatively high percentages (approximately 75 percent) testified that coral bleaching either had negatively impacted their overall dive experience or would impact their destination choice[4]. These results indicate that increased public awareness on coral bleaching in the future may create a more discerning diving customer, increasing the influence of coral reef condition in destination and activity choices.

[3]Low awareness among survey respondents may be because study surveys were undertaken in areas that were heavily bleached and knowledgeable divers had already exercised their decision to go elsewhere.

[4]This strong relationship was true in cases of direct questioning about coral bleaching; more indirect approaches attempting to link bleaching impacts with willingness to pay were less clear in suggesting how reef degradation impacts consumer welfare.

A Strategic Approach

There are two key factors limiting the development of responses to mass coral bleaching. The first is the major issue of global climate change as a causal factor. The second is the lack of scientific answers to important management questions. The consensus among the mini-symposium presenters was that while these challenges should be accounted for in a strategic response to mass coral bleaching, neither global warming nor uncertainty should preclude some sort of earnest response. Managers can begin by implementing known approaches to foster coral resiliency and recovery in damaged coral reefs. Adaptive management is one way to address scientific uncertainty, and should include monitoring of ecological, socioeconomic, and management variables to evaluate and adjust strategies. Such a systematic response brings the discussion back to: what to do if mass coral bleaching is an inevitable result of global climate change? It is well understood that manifestations of global warming will vary on-the-ground in localized situations. Within this variation is the opportunity to identify bleaching-specific responses. An adaptive approach, rich in monitoring and evaluation, will be able to identify and respond to these localized opportunities. Ultimately, an important step will be to address climate change itself. The elements of such an approach, including guiding principles and strategies as identified in the mini-symposium, are summarized here.

Principles & Strategies

The approach described above is founded on several guiding principles:

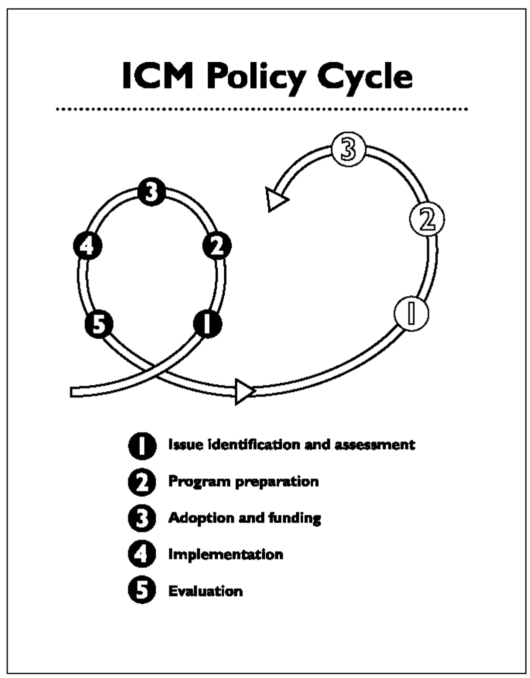
- Mass coral bleaching is one of a number of stresses that cumulatively threaten coral reef ecosystems and must be addressed within this larger context.
- Management can be undertaken in the absence of complete scientific understanding of the specific causes and consequences of mass coral bleaching and should be implemented adaptively.
- Management should aim to create situations that maximize the potential for coral reef resiliency to mass bleaching and recovery after these events.
- Management-oriented research is needed to elucidate the conditions that bolster coral resiliency and promote recovery as well as to refine predictions on the extent and implications of future events.
- Ultimately, responding to mass coral bleaching will include addressing global climate change through reductions in CO^2 emissions.

These principles suggest management, research and policy responses that will be discussed in more detail below. Management responses can generally be divided into strategies directed toward coral reef ecosystems and strategies directed exclusively toward mitigating the socioeconomic impacts of mass bleaching on coastal communities. To address the ecological issues, the principle articulated here—that management should aim to create situations that foster coral resiliency and recovery—suggests two strategies. The first strategy is to implement responses that generally promote coral health. This recommendation recognizes that bleaching is one of many stressors with the potential to impact coral reefs. It is also possible that healthier reefs will be less vulnerable to mortality from bleaching; however, this assumption needs to be further investigated by the research community. The observation by Westmacott et al. in this volume that it was the more pristine reefs in the Indian Ocean that were worst affected by bleaching is a concern. The second strategy is to identify and pursue responses that are specific to bleaching. Opportunities for bleaching-specific responses could take advantage of local conditions, as suggested above. Additionally, better understanding of mass bleaching and coral reef ecology may clarify further response options. These options might include, for example, adjusting fisheries management on bleached reefs to protect species population composition and species that are useful in maintaining coral health during bleaching events (i.e. herbivores that scrape algae off dead coral maintaining suitable surfaces for coral larvae recruitment).

Responses

Management, research and policy responses to mass coral bleaching will be most effective when coordinated. The Reaser paper thoughtfully considers the type of "symbiosis" needed to achieve coordination between research and policy efforts. Their conclusion is applicable to coordination of all three areas – management, research, and policy – and relies on researchers having the courage to bring their core competency to other disciplines and managers and policy makers being willing to listen and respond to this more complex information. Such an exchange needs an appropriate framework – such as ICM – to operate in. ICM has been described as a cycle that includes issue identification, planning, implementation, and evaluation (Figure 1). ICM is appropriate because, conscientiously implemented, it incorporates adaptive management overtly, has the capacity to assimilate the multiple stressors which cumulatively impact reef condition, and has already been promoted as the recommended response to related issues, including global climate change and coral reef management (IPCC, 1995; ICRI, 1998).

ICM promotes coordinating resource management at different geographic scales, from sub-national to local. At the regional and national level, this process involves explicit policy development and is primarily concerned with establishing the financial resources and technical competency needed to support local programs. ICM is directly implemented at the local scale of individual reefs and sections of coastline, where the guidance developed at broad scales is translated into context-specific actions, resulting in a nested system of management. ICM at all levels will follow the same process of issue identification, planning, implementation, and evaluation.



Issue Identification: ICM planning should be based on identification of the salient causes and consequences of the ecological and socioeconomic impacts of mass bleaching. The identification and planning elements of ICM are likely to highlight many gaps in current scientific information that are important from a management perspective. These questions need to be prioritized into a research agenda and incorporated into larger policy initiatives. Addressing a global phenomenon at a local scale, which is the goal of management for mass coral bleaching, is complex and challenging. Achieving effective management will require distilling critical issues to a level at which we can address them, without simplifying useful complexity that harbors opportunities for response. Issues of central concern in developing an effective response to mass bleaching are summarized in Table 1.

Table 1: Ecological and socioeconomic issues of central concern in developing a strategic response to mass coral bleaching, including their causes, potential consequences and related research questions.

Ecological Issues	Causes	Potential Consequences	Priority Research Questions
Mass mortality of corals	Coral mortality caused by rising sea surface temperatures as global warming proceeds.	Decreased coral vitality results in ecological shift of coral reef communities to other states, resulting in reef erosion, loss of structural complexity and biodiversity.	Can coral-zooxanthellae symbioses adapt to changing temperature conditions? What factors contribute to resilience of reef communities and reduced mortality of corals?
Low recruitment of corals	Widespread mortality of corals results in low reproductive success and depressed recruitment of new corals to degraded reefs.	Failure of coral reef assemblages to recover to pre-bleaching status, exacerbating degradation.	What factors facilitate coral reproductive and recruitment success following mass mortality? Can artificial means be used to facilitate reproduction and recruitment of corals?
Declining area of functional coral reef communities	Depressed recruitment and recovery of impacted coral assemblage results in declining area of functional coral reef communities.	Loss of coral reefs and concurrently their ecological & socioeconomic values on local to global scales. Declining biodiversity of tropical marine coastlines.	What actions are viable to facilitate restoration and/or rehabilitation of coral reef communities? What restoration/rehabilitation actions reduce losses in biodiversity on degrading reefs?
Socioeconomic Issues	**Causes**	**Potential Consequences**	**Priority Research Questions**
Fisheries	Coral reef degradation impacts fish stocks, reducing abundance and diversity and shifting population composition.	Reduced fish catch results in lost protein, income and money for foreign exchange. Losses in subsistence fisheries may result in malnutrition and total loss of livelihood where alternatives are unavailable.	How will coral bleaching impact fishery abundance and diversity and what measures can minimize these impacts and facilitate coral recovery? How can impacted fishers best be assisted financially and through opportunities for supplemental livelihoods?
Tourism	Actual or perceived coral reef degradation impacts tourist destination and activity choices and satisfaction.	The diving industry and diving destinations experience revenue losses as knowledgeable tourists select alternative activities or destinations. Degraded conditions reduce diver satisfaction.	To what extent does reef quality influence tourist activity and destination choices and satisfaction? What strategies will assist diving destinations in retaining their status and reputation despite degraded reef condition?
Coastal Protection	Eroded reefs fail to dissipate wave energy threatening the erosion of valuable real estate.	Coastal barriers are constructed at significant economic expense detrimentally impacting coastal aesthetics.	How can existing measures for coastal protection, and projections of erosion be modified to incorporate the effects of mass coral bleaching?

Planning: Based on the strategy proposed here, ICM planning should begin by focusing on general coral reef management, which considers the multitude of stressors that cumulatively have the potential to impact reef condition. Efforts that fail to recognize this larger context may win some battles, but will ultimately lose the war. There are many good texts that discuss general reef management, and many of the basic principles are highlighted in Wells et al. Essentially, it involves identifying reefs and the circumstances that currently threaten reef condition or have the potential to do so. Based on the threats identified, strategies are implemented to address both stressors that impact reefs directly, for example, destructive fishing or anchor damage from diving boats, and indirectly, such as sedimentation or pollution. These strategies can include land-use and fishing regulations, zoning schemes including MPAs, and passive or active rehabilitation of damaged corals. Additionally, general reef management should include monitoring protocols to keep a pulse on reef health, and public education initiatives to create and maintain a constituency for reef management and conservation.

One of the threats that needs to be considered during the planning stage is coral bleaching. The bleaching consideration should be superimposed on the composite picture already established for the reefs being managed. Based on our current understanding of coral bleaching, predictions should be made about the likely impacts of future events under optimistic, average, and pessimistic scenarios. Salm et al. describe many of the ecological considerations that should be included in such an impact analysis. Key questions that need to be addressed in the assessment are:

- Which reefs are most and least likely to be impacted by coral bleaching?
- Are the reefs expected to be more resilient “source” or “sink” reefs?
- Are “source” reefs that are expected to be resilient currently threatened by another anthropogenic stress that can be addressed by management actions now? What actions are required?
- What are the likely impacts to diving destinations in the area being managed?
- To what extent will these destinations and diving operations be able to diversify to maintain their reputation and status should local reefs become degraded?
- How will reductions in catch affect local fishers, including subsistence fishers?
- To what extent are opportunities for alternative or supplemental livelihood available to fishers should the fishery collapse as a result of coral bleaching?

Contingency plans can then be prepared to most efficiently respond to likely or catastrophic impacts. Contingency plans should include emergency response protocols for both research and management. The research protocol should establish a procedure for documenting the severity, extent, and recovery from the bleaching event in detail so that the experience can be incorporated into future management efforts. The management protocol should be prepared to offer emergency assistance to fishers – especially subsistence fishers – and tourism operators that are unable to avoid losses due to coral bleaching. Management protocols should include a procedure for reviewing and responding to scientific assessment of the bleaching event as it becomes available. Such review may suggest creating or revising MPA boundaries to protect resilient source reefs from other anthropogenic stresses, facilitating post-bleaching recovery.

Contingency plans should also include non-emergency responses that can be implemented either prior to or following bleaching events. Applicable responses were presented by Wells et al. and are summarized in this compendium. Some of their suggestions include:

- Diversification of local tourism industries and/or opportunities available to fishers.
- Public education on mass bleaching to help prepare communities for bleaching events and create a constituency for climate change.
- Briefing government representatives on the implications of mass coral bleaching locally, so that these considerations can be voiced in international forums.
- Assessing the feasibility, cost and likely success of coral reef restoration or rehabilitation.

Implementation: Good plans that cannot be implemented are not really good plans. Implementing the planning and response recommendations described here in the tropical developing nations that host most of the world's reefs will require funding and human capacity that does not currently exist in these countries. It is imperative that policymakers take action to address this gap, leverage the resources needed, and facilitate the initiation of impact analysis and contingency planning. Since the tropical developing nations that are most likely to be affected by mass coral bleaching are also the least responsible for global warming, appropriate policies should be established to compensate for this inequity through the provision of this assistance.

Funding and human capacity must be made available at a local level to implement management, monitoring, and, when necessary, rapid response. Rapid response assessments of bleaching will be most useful to management efforts when they are comparable, meaning that assessments must be standardized and funding must be available to implement these efforts in a timely manner. Standardization requires adopting a monitoring protocol, establishing training programs on the selected technique, and facilitating access to expert advice for less experienced researchers.

Evaluation: Evaluation is both the basis for genuine adaptive management, and a forum where cohesion between research, management, and policy communities can significantly enhance the effectiveness of response. Adjustments to mass coral bleaching response strategies should reflect the best scientific information. More informed predictions as to the severity and extent of future mass bleaching events will assist the policy community in its difficult work. There are already good examples of evaluation studies at both the global scale (e.g. the ecological synthesis by Wilkinson, 2000) and the regional scale (e.g. Souter et al., 2000 includes regional evaluations of both the ecological and socioeconomic impacts of mass bleaching in the Indian Ocean region). The next step, as argued by Reaser et al., is to translate this new information into strong policies.

Conclusions

The extensive coral mortality caused by the 1997-98 mass coral bleaching event raised serious concern over the ecological and socioeconomic implications of bleaching events, the expected severity and frequency of future events, and the future of coral reefs. Three years after this event a preliminary picture of its impacts is coming into focus that underscores the necessity for management, policy, and research responses to mass bleaching. The ecological impacts of mass coral bleaching have been demonstrated to be severe, with massive losses in coral cover and diversity, as well as in other coral reef-associated organisms. These losses occurred from local to oceanic scales, and with the increasing frequency and severity of ENSO events driven by global climate change, the degradation of coral reefs due to mass coral bleaching can only be expected to increase. Economic losses to reef-dependent tourism are the most significant economic impacts observed thus far. However, the potential for serious socioeconomic impacts to reef-dependent fishing communities as degraded reefs continue to erode justifies critical concern and attention.

Effective responses to mass coral bleaching are hampered by scientific uncertainty, our inability to respond to global climate change in the short term, and insufficient financial and human resources. However, these challenges cannot justify inaction. Rather they underscore the primacy of developing adaptive strategies and capacity so that countries and communities are prepared for future mass bleaching events. Responses should reflect that mass bleaching is one of many stressors cumulatively affecting coral reef communities and begin by implementing actions that promote coral health generally. Mass bleaching is one of these stressors and necessitates identifying and planning for the expected ecological and socioeconomic impacts from future events. Effectively implementing adaptive management will require support from both the research and policy communities to provide the technical information and financial and human resources needed for success. The policy community faces two great challenges. First, to commit the resources needed for successful implementation of coral reef management in the developing nations that host most of the world's coral reefs. Second, to address global climate change through reductions in CO^2. Mass bleaching creates a broad constituency and justifies efforts to address global warming, as it foreshadows the potentially larger impacts to come about through unabated global warming.

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THE SCIENCE BEHIND CORAL BLEACHING: PRIORITIES FOR RESEARCH AND MANAGEMENT

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ABSTRACT

The 1998 mass bleaching that occurred on the Indo-West Pacific coral reefs called attention, once again, to the gravity and urgency of the consequences of this phenomenon, of which we have rather limited scientific understanding. The symbioses among clades or species of zooxanthellae and hundreds, if not thousands, of species of invertebrates no doubt undertake different modes that may have arisen independently along several host taxa. If this is the case, there is no shortcut to understanding the nature and consequence of bleaching. Scientific approaches are necessarily numerous, with the obvious need to start to identify the physical and chemical factors at different temporal and spatial scales that initiate the dissociation of host and symbiont. Organismal or physiological processes on the part of the host, and of the symbiont, need to be studied better. The attendant mortality of associated non-symbiotic species, on the occasion of bleaching events, needs to be adequately understood, as this will contribute to the understanding of the morbidity of the hosts of the zooxanthellae. In addition, the ecosystem effects and responses related to bleaching are just beginning to be investigated, but are no less important than the organismic reactions. Managers and decisionmakers often call for interventions when disaster strikes. In the case of bleaching, is the science well enough established to justify significant investments of time and resources? Both short-term and long-term responses are considered briefly.

INTRODUCTION

1998 will long be remembered in the Philippines, the Indo-West Pacific, and possibly the rest of the tropical world, as the year when vast areas of coral reefs turned white. While some bleaching events started in 1997, and others occurred later, we take 1998 as the most significant year because of personal exposure to the mass mortalities of giant clams, corals, other invertebrates, and even reef fishes.

This symposium (The Coral Reef Symposium) is replete with scientific presentations on various aspects of the 1997-1998 El Niño and attendant bleaching phenomena. With so many papers being presented,there may be precious little that we can contribute in terms of subject matter, possibly a little bit more in terms of treatment and emphasis. Many of us are aware of excellent review papers on bleaching, such as those of Barbara Brown (1997) presented in Panama, the earlier work of Glynn (1993; 1996) and, more recently, the papers of Hoegh-Guldberg (1999), Pomerance (1999), and Wilkinson (2000), to list some. It will be difficult to do better than they. We choose to wander on a path that meanders through symbiosis, zooxanthellae and physio-

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logical processes, to the bleaching phenomenon and its ecosystem implications. Then on to management steps addressing the issues related to bleaching and mass mortalities, picking up along the way a few references that have not been cited, and, hopefully, in this way contributing to a better understanding of the issues. Another feature of this paper is the inclusion of some material from giant clam work, both from our laboratory and from other sources. It must be borne in mind that whatever the host, we seem to be dealing with the same suite of symbionts. The giant clam is a good experimental animal to work with because of the large quantities of both host tissue and zooxanthellae for analysis, in addition to its being a potentially sensitive indicator of disturbance (Belda-Baillie et al., 1999).

THE NATURE OF THE SYMBIOSIS

Living together used to be considered a more permanent arrangement between two individuals. Today, corals and their symbiotic dinoflagellates also seem to be more fickle in their relationships. Whether this is a recent trend, or has been the case since the evolution of the relationship, will be difficult to determine and we will not venture an opinion. We will briefly go back in time to glimpse the start of this symbiosis, bearing in mind that the association is a potential mechanism through which the partners may be able to diversify into a habitat that was previously unavailable to one or both without the other (Norris, 1996).

Dinoflagellates existed in the Paleozoic era, with a major diversification occurring in the early Mesozoic. All the families found in the Triassic have modern counterparts today. Also, during this time, some of the Triassic corals were already “zooxanthellate” (Fensome, 1996). In foraminiferans, photosymbiosis appears to have been the catalyst for their radiation, but was not the driving force of their evolution. Co-evolution with scleractinian corals may have influenced dinoflagellate radiation. Evidence of this is found in the observation that the first appearance of scleractinian corals was coincident with that of dinoflagellates. Also, the fact that the corals’ symbiotic dinoflagellates resemble the Late Triassic genus Symbiodinium lends additional support to the above hypothesis (Fenstome, 1996). However, there is no reliable evidence of host-symbiont co-evolution. Although there are instances that appear to be co-evolutionary, in general, Maynard Smith’s fundamental premises of co-evolution are not found to be true in algal-marine invertebrate symbiotic associations (Trench, 1997).

It should be borne in mind that today the combinations and permutations of hosts and symbionts in the algae-invertebrate partnership do not amount to a trivial number, especially if the protozoan hosts, principally foraminiferans, are added. Table 1. presents a summary of the array of symbioses among algae and their hosts, which may be protists or invertebrates. The actual manner in which the partnerships arose is beyond the scope of this paper. Suffice it to say that they may have arisen in different ways at different periods of geological time. Today, we can simply refer to the modes of infection.

In most cases, zooxanthellae are located in vacuoles within the endodermal cells of the host. In the giant clams, however, they are intercellular or extra-cellular and are actually restricted to the zooxanthellar tube system. This system connects with the digestive diverticula that originate from the stomach and branch into other organs, such as the adductor muscle and the mantle (Norton, 1995). In a very recent paper, Morton (2000) describes the situation in the zooxanthellate cardiid, Fragum erugatum, where the zooxanthellar tube system links the digestive diverticula of the stomach with the kidneys.

Table 1. Symbiosis: Known Algal Taxa with Invertebrates and Protists *(Modified from Nybakken [1998] & Trench [1993])*

ALGAL SYMBIONT GROUP	ALGAL TAXON	HOST TAXA
Zooxanthellae	Dinophyceae	Protista, Porifera, Cnidaria, Platyhelminthes, Mollusca
	Haptophyceae	Protista
	Chrysophyceae	Protista
	Bacillariophyceae	Platyhelminthes, Protozoa*
	Cryptophyceae	Protozoa
Zoochlorellae	Prasinophyceae	Platyhelminthes, Protista
	Chlorophyceae	Cnidaria, Protista
Cyanellae	Cyanophyceae	Porifera, Protista, Echiuroidea
Prochlorophyta	Prochlorophyceae	Urochordata
Rhodophyta	Bangiophyceae	Protozoa
Chlorophyta	Chlorophyceae	Mollusca, Cnidaria, Protozoa, Porifera

There are two main modes of infection of the hosts, closed or open symbiosis. Closed symbiosis occurs when the algal symbionts are transmitted directly to the host's offspring, as is the case in the foraminiferans, radiolarians and coelenterates. Closed inheritance may take the form of direct transmission via the egg, wherein the zooxanthellae are located within the egg itself. Or infection may occur once the eggs are fertilized, after which they adhere to the zooxanthellae that have been released by their parents. On the other hand, open symbiotic transmission occurs when the eggs are released without the algae, and the larval or juvenile stages of the potential host acquire them from the environment, as is the case with the giant clams (Trench, 1998). The density of zooxanthellae in corals ranges from 1.0 to 2.0 x 10^6 per square centimeter (cm^2) of coral surface, while in giant clams, densities range from 44 to 1,300 x 10^6 per cm^2 of mantle in different species and sizes of the host.

On the whole, zooxanthellae carry out photosynthesis and mediate nutrient flux between the environment and the host. In coral, they subsidize the hosts' needs for respiration and growth by translocating fixed carbon to the host, allowing for accelerated calcification (Muscatine, 1991). Approximately 65.5–96.7 percent of the carbon fixed daily by zooxanthellae is made available to the host in the form of glycerol, lipid, and amino acids, greatly benefiting the coral. Thus, photoautotrophic coral have their carbon demands for

Table 2. The Percent Contribution of Translocated Photosynthates (TP) and Absorbed Ration (AR) to Respiration Plus Growth in 4 Species Of Tridacnidae *(Computed from Klumpp and Griffiths 1994)*

Species	Size of clam (g tissue dry wt)	Requirement (mgC clam^{-1} day^{-1})	TP (%)	AR (%)
Tridacna gigas	0.1	3.2	190.6	112.5
	1.0	14.7	204.8	61.2
	10.0	67.0	219.9	33.4
	100.0	309.6	233.3	18.0
T. crocea	0.1	1.7	205.9	11.8
	1.0	7.1	235.2	21.1
	10.0	29.2	272.6	42.8
T. squamosa	0.1	1.1	118.2	9.1
	1.0	6.9	156.5	13.0
	10.0	43.0	207.4	18.8
	100.0	268.4	273.7	27.8
Hippopus hippopus	0.1	0.9	33.3	44.4
	1.0	4.6	76.1	43.5
	10.0	30.2	153.6	37.1
	100.0	258.2	237.7	24.1

respiration and growth subsidized by the zooxanthellae. The coral also uses ~ 4 percent of the translocated carbon to synthesize new animal biomass. For giant clams, the potential contribution of the photosynthates can be three times the amount needed by the host on a daily basis. This contrasts with the average contribution of filter feeding to the requirements of the clam. In virtually all species studied, and the different size classes used, the heterotrophic nutrition alone is inadequate. (Table 2.)

Zooxanthellar growth, on the other hand, appears to be uncoupled from its photosynthesis. The rate of growth is low, with the zooxanthellae standing stock maintained at a constant level (Muscatine, 1980), even though the photosynthetic rate may be high. In return, the zooxanthellae obtain nutrients directly that would be otherwise scarcely available to them in the oligotrophic waters of coral reefs. Zooxanthellae are also protected from damage from solar radiation. Although the algae-host relationship is characterized by its specificity, this does not mean that there is exclusive one-to-one association of one host with a specific alga. Rather, it is an association resulting from several mechanisms that prevents the promiscuous random formation of combinations, while at the same time, it allows for the probability of the occurrence of others (Iglesias-Prieto, 1996).

The observation of a single host's having polymorphic symbionts is a result of this specificity. Rowan et al. (1995) deal with the diversity of zooxanthellae in corals. Individual giant and cardiid clams can harbor a distinct or heterogeneous assemblage of zooxanthellae (Baillie et al., 2000; Carlos et al., 2000) as examples of populations of conspecific hosts that may harbor a number of distinct zooxanthellae. An implication of this is that hosts with a wide range of symbiont associations may have an adaptive advantage during periods of environmental perturbation (Trench, 1996; Rowan, 1998).

The characteristics of the association, given the large number of varied combinations, are the outcome of several factors: taxonomic specificity, environmental parameters, mode of symbiont acquisition and the degree of symbiont circulation within the host (Baker, 1997). Branching corals have been found to harbor less diverse types or clades of algae relative to massive corals. This observation has been explained as a result of the host's selecting a single zooxanthellar taxon best suited to the range of light it will encounter while it circulates within the host. Increased circulation found in branching coral results in decreased zooxanthellar diversity, while low circulation within massive corals allows for multiple taxa to be present to subdivide the light gradient (Gladfelter, 1986 in Baker, 1997).

Zooxanthellae

While the typical coral reef buff is aware of the symbiosis and of the host, knowledge of the symbiont is generally more limited. It is not our purpose to get too involved in the biology of the zooxanthellae, but it is appropriate to review some of the conventional knowledge about this group of dinoflagellates.

There are eight genera in four or five orders of dinoflagellates (Pyrrhophyta or Dinophyta) that are known to form symbiotic associations with marine invertebrates. There are four orders, if Symbiodinium is placed in the order Gymnodiniales, and five orders, should Symbiodinium be placed in the order Suissiales. The most common genus of zooxanthellae is the Symbiodinium, which contains three clades or groups (A, B, C). The first clade (A) occurs in corals found in very shallow water and is exposed to high irradiance. They have been found to be opportunistic in disturbed environments and are normally the first to occupy space opened up by zooxanthellae expulsion (Rowan, 1998). Clade C is at the other end of the spectrum. It occurs in corals found in deep waters with low irradiance, and is found to be preferentially lost from corals during a bleaching episode (Rowan et al., 1997). Little is known about B and a putative D.

Physiological Processes

The symbiosis between the algae and the host is regulated and maintained by a number of mechanisms. Observations that taxonomically similar hosts harbor dissimilar symbionts, while closely related symbionts may be found in association with phylogenetically distinct hosts, point to the recombination of host and symbiont (Trench, 1997). Experiments conducted at our institute have shown that the genetic make-up of the zooxanthellae in cultured juvenile clams may be different from that of the zooxanthellae originally used to inoculate the veligers (Belda-Baillie et al., 1999). This could be interpreted to indicate that the hosts change their symbionts over time from the external environment or that the original zooxanthellae from the inoculum have genetically diversified.

Host factors (HF) also play an important role in the normal functioning of the symbiosis. These HF are chemical cues released by the host, which evoke the release of fixed carbon compounds by the zooxanthellae (Gates, 1995).

The regulation of zooxanthellae standing stock density, although documented, has not been fully understood. In fact, regulation has only been proved in anemones (Titlyanov, 1996). Several mechanisms may be at work. Algal regulation by the host may involve the host cells dividing in synchrony with the algal populations. The host may also be releasing cues or withholding nutrients which directly affect the algae, either inhibiting or stimulating growth. Another mechanism proposes that the host cells regulate the zooxanthellae by exocytosis, or digestion. However, hermatypic corals can expel only 0.1–1 percent of their algal standing stock per day. This rate is too low to balance out the zooxanthellae replenishment rate of 0.5–10 percent per day (Titlyanov, 1996).

THE BLEACHING PHENOMENON

Reports of coral bleaching go back over a century to the 1870's (Glynn, 1996). Bleaching, a term used to describe the observed paleness of the coral in response to some external stress, is a result of many possible events—the loss of zooxanthellae, the loss of photosynthetic pigments alone or "photobleaching," the degradation of the cells housing the zooxanthellae—or a combination of these. The host corals then appear pale as the aragonite limestone skeleton becomes visible through the transparent tissues of the polyps (Hoegh-Guldberg and Smith, 1989). In giant clams, the bright mantles of the bivalves become completely white in severe cases, in contrast to some corals whose calcareous skeletons may manifest a pastel hue of yellow or violet.

The various factors that bring about bleaching have been reviewed by a number of authors and need only to be mentioned briefly here. These include temperature stress in its various manifestations, i.e. degrees elevated, duration, (Jokiel, 1990; Muscatine, 1991; Iglesias-Prieto, 1992; Winter, 1998; Brown, 2000), excessive solar radiation (Gleason et al., 1993; Brown, 1994; Anastazia et al., 1995; Lesser, 1996), reduced salinity (Meehan, 1997), bacterial infection (Kushmaro et al., 1997; Banin, 2000) and cyanide (Jones et al., 1999). Hoegh-Guldberg (1999) included copper ions and pesticides, while Glynn (1996) included sub-aerial exposure, sedimentation and oil as contributory factors.

The effects of bleaching are multiple. Jokiel (1977) mentioned the inability of the coral to maintain normal rates of production and the resulting decrease in the photosynthesis to respiration (P:R) ratio, which translates to a reduction of the autotrophic ability (Jokiel, 1990), which, in turn, may lead to the organism's death. Similar effects may be expected in other symbiotic invertebrates, particularly the giant clam, where, in addition, the zooxanthellar tubular system atrophies as a consequence (Norton et al., 1995). Whether this is a permanent condition is unknown, but the persistence of a number of half-bleached clams in our ocean nursery lends evidence to the possibility that some damage to the system may be permanent, while in some cases, it may be reversible. Some bleached clams recovered completely, while others died.

Iglesias-Prieto (1992) found that photosynthesis is impaired at 30°C and ceases completely at 34-36°C. However, respiration did not cease completely, showing that the cells were not dead. If the coral-algal relationship is highly functional, then the inability of one or both partners to maintain the normal rates of production should have serious consequences. Elevated temperature-induced bleaching has resulted in the failure of the coral to maintain normal rates of production, a decrease in P:R ratio, a reduction in autotrophic ability and, depending on the intensity and persistence of the bleaching event, the organisms' succumbing as the host loses the symbiont (Jokiel, 1990).

Adaptation

In response to a change in water temperature, marine organisms may either acclimate by modifying components of their physiological processes to perform better at the new temperature, or they may adapt via selection of individuals within the population that are more able to cope with the new temperature regime. This adaptation involves natural selection.

In 1993, Buddemeier and Fautin put forward the hypothesis that coral bleaching is an adaptive mechanism (Adaptive Bleaching Hypothesis). This is based upon observations that there are consistent habitat differences in bleaching resistance in a given area. Corals in habitats that were exposed to more variable stress tend to be less bleached than those in more normally equable environments (Cook et al., 1990). Also, despite apparent environmental adaptations, there are consistent taxonomic differences in vulnerability to bleaching, and in mortality, in a particular area.

Between the two partners, the rapid potential regeneration time of the symbionts, compared to the hosts, appears to point to the symbionts as being evolutionarily more capable of responding to local conditions. Bleaching is therefore seen as an opportunity for creating a different host-symbiont combination with features that are more robust under the altered conditions (Buddemeier and Fautin, 1993). The specificity of the relationship then changes as a response to environmental alteration. The heterogeneity of the algae in the host at any time is then seen as a reflection of many interacting factors: the competitive advantage of some compared to others, the time since the most recent stress, frequency of the stress and local diversity of the zooxanthellae.

However, Hoegh-Guldberg (1999) questions this Adaptive Bleaching Hypothesis because there is no known observation that corals expel one variety of zooxanthellae, when heat-stressed, while at the same time they take on more heat-tolerant varieties. Although there have been observations of selective loss of one type of zooxanthellae during heat stress (Rowan et al., 1997), this, in itself, is not a firm indication of bleaching as an adaptive mechanism. If the observations were that the areas that had lost zooxanthellae were being repopulated by more heat-tolerant varieties as the stress was being applied, then the above hypothesis might have some basis (Hoegh-Guldberg, 1999). Also, the fact that bleached corals still have substantial concentrations of their original zooxanthellae populations suggests that bleaching may have more to do with the expulsion of those components of the symbiosis that are damaged by the stress, than the total removal of one particular population.

Resilience

The bleaching susceptibility of reef corals has been shown to have patterns that follow algal genotypic differences within a colony (Rowan et al., 1997). However, recent experiments have shown that experience can also shape coral bleaching patterns in a colony. Brown et al. (2000) demonstrated that western surfaces of Goniastrea aspera colonies in reefs of Phuket, Thailand have developed a relatively improved tolerance towards the combined stress of temperature and solar radiation, compared to eastern surfaces, as a result of their history of exposure to increased photosynthetically active radiation (PAR). Furthermore, the seasonal variation in the upper thermal limits of Pocillopora damicornis from an inshore reef in the central Great Barrier Reef suggests that coral species may have some potential to acclimatize to elevated temperatures (Berkelmans and Willis, 1999). Acclimatization of corals to thermal stress has also been shown on a more reef-wide scale, where corals on the shallow reef, normally exposed to higher temperatures were less affected by bleaching than corals on the reef slope (Marshall and Baird, 2000). The same study reported that the extreme range in bleaching susceptibility of taxa, which characterize assemblages, drives the variation in bleaching severity among sites.

Reef Recovery

The ability to predict recovery of reefs affected by bleaching has been shown to vary, depending on a number of factors that include: succession sequence and diversity of a reef; past and present dynamics of reef communities; environmental tolerances and life-history strategies of the dominant species; secondary disturbances, such as predation and erosion; and the magnitude of disturbance (Brown and Suharsono, 1990). Fisk and Done (1985) found notable recovery within two years in the Great Barrier Reef with the rapid growth of acroporid and pocilloporid corals and hydrocorals that survived the 1982 bleaching. After five years, Brown and Suharsono (1990) reported lower rates of recovery on reefs in the Java Sea that experienced 80-90 percent mortality. Coral cover had increased to about 50 percent of its formal level, but rates and patterns were markedly different in two initially similar reef flat communities. This was probably due to the predominance of the bleaching-susceptible Acropora species whose death and breakage of branches produced an unstable rubble surface that was unsuitable for coral recruitment. Glynn (1996) reviews the situation in the tropical eastern Pacific, where studies reveal relatively slow recovery in severely impacted regions. The recruitment of corals onto reefs has been erratic and slow and many of the remaining severely impacted reefs are undergoing rapid bio-erosion. He states that if recovery is defined as the replacement of 100- to 300-year-old reef frameworks and massive coral colonies, then full community restoration will probably not occur for several hundred years.

Related Mass Mortalities

The focus of attention of climate change effects and of the El Niño in the marine environment is coral bleaching. This is probably due to the dramatic visual effect of the whitened corals, the mass media, and the growing number of coralophiles. In some occurrences of elevated temperatures on shallow water environments, there may be attendant mass mortalities of associated organisms. In a short note at the end of the last El Niño (Gomez and Mingoa-Licuanan, 1998), we called attention to the fact that we witnessed mass mortalities of giant clams, other invertebrates, and reef fish at our field sites in Bolinao, northern Philippines. While many of the clams died bleached, a significant number died unbleached, indicating an acute stress that took effect faster than the normal consequence of bleaching.

Hence, when talking of the effects of climate change and the El Niño phenomenon, we should not be limited to a discussion of the bleaching phenomenon. In some situations, the thermal stress, the high solar radiation, and the calm winds that reduced circulation may contribute singly, or in combination, to the demise of reef flat organisms. Water temperatures at the Bolinao Marine Laboratory approached 35°C. The larger clams (>30 cm shell length) were more severely affected than the juveniles. The fact that reef fish, including eels, damsels, blennies, puffers, and catfish, bellied-up points to respiratory stress, probably due to hypoxia and high temperatures over extensive areas of the shallow reef flat. These weak swimmers, together with sessile and slow moving invertebrates, such as sea urchins, were unable move or transfer to more favorable environments and, thus, suffered mass mortalities.

The observation of fewer mortalities at the ocean nursery with an abundance of seagrass, principally the tall Enhalus acoroides, in contrast to the unvegetated areas, may indicate either or both of two factors. These are the possible beneficial effects of shading (Jompa and McCook, 1998) and the higher oxygen content of the surrounding waters, contributed by the plants, although this was not actually measured.

Ecosystem Implications

The mass mortalities involving species other than corals leads to a consideration of the ecosystem implications of bleaching in particular, and high solar radiation and elevated temperatures in general. It is clear that radiation and temperature can have direct effects on other components of the ecosystem besides the corals. Little attention has generally been placed on this. More attention has been focused on the consequences of corals bleaching and subsequently dying.

The most common observation is that extensive coral mortalities are often followed by the overgrowth of the dead skeletons by algae, whether turf or fleshy, with the net effect, or so it is claimed, that coral recruitment is delayed if not prevented. Another assertion advanced is that this is due to the fact that in many overfished reefs, the normal populations of herbivores that should keep the algae in check are no longer there in effective numbers, whether we are talking about fish (see Öhman et al. below) or invertebrates. While plausible, these theories need validation with some hard numbers and comparative, controlled studies. In our judgement, this is definitely a researchable area, as we cannot be continually staking our good reputation as scientists, without the hard science to back us up.

A recognized actor in the “after bleaching, what” studies, is Peter Glynn, whose work following the 1982-83 El Niño is well-known. In 1985 he examined three corallivore species in an eastern Pacific patch reef that suffered 50 percent coral mortality following the 1982-1983 bleaching event. Population densities of the ovulid gastropod Jenneria pustulata were reduced by 86-100 percent due to the loss of its food source and subsequent death by starvation. In the relatively wide-ranging corallivores, Acanthaster planci and Arothron meleagris, however, population densities were comparable to those of predisturbance levels, and individuals were observed to feed on the dispersed surviving coral prey. Acanthaster were also observed to feed more frequently on partially bleached pocilloporids where crustacean guards had reduced agonistic behavior (to 26 percent), their usual defensive response. Arothron was also observed to switch its diet to coralline algae (Guzman and Robertson, 1989). Bio-erosion following the event was monitored, as well (Glynn, 1988). A 25–37 fold increase in the population densities of the sea urchin Diadema mexicanum, due to high recruitment, was observed in 1984 with a corresponding increase of the same magnitude in bio-erosion rates at the principal coral reef zones in Panama. Quantitative surveys of dead borers in coral (Lithophaga spp. and boring sponges) also indicated enhanced recruitment following El Niño years (Scott et al., 1988). Measurements of internal bio-erosion were found to be in approximate balance with reef calcification.

A 39 percent increase in fish numbers and a shift in composition to a more herbivore-dominated fish community were reported in Tutia reef, Tanzania (Öhman et al., 1999). This change may have been an indirect effect of the 88 percent coral die-off which led to an increase in algal growth following the 1997-1998 El Niño.

Studies on ecosystem implications following the 1982-83 El Niño are not numerous. It is hoped that with the recent occurrence, many more investigations are currently being carried out to understand better the impacts of this recurring event.

Socioeconomic Considerations

For the coastal developing countries, the most important socioeconomic considerations of the mass bleaching events are likely to be fisheries and tourism. Although many coastal dwellers are dependent on fish stocks for their livelihood, to date there have not been well-documented cases of large-scale negative impacts. Even the relatively well-studied fishery of Kenya showed no immediate or prolonged drop in fish catches after the serious bleaching event. This may have been due to the fact that the reef fishery often consisted of species that are not coral-dependent, such as seagrass-feeding rabbitfish, herbivorous parrotfish, and planktivores (Goreau et al., 2000). Tourism-dependent small island states may have more to be concerned about, if their bleached reefs result in fewer visitors. The impacts of the 1997-98 mass bleaching on these areas are still being monitored, and we may have to wait a bit longer to get the full results, although preliminary information from the Maldives has not substantiated the apprehensions of some observers. Other presentations during this symposium will contribute to the better understanding on the approaches and results of studies addressing these issues and others, like the longer-term implications of potential bio-erosion on beaches.

Wilkinson et al. (1999) made a preliminary attempt to determine the socioeconomic impacts on Indian Ocean coastal areas. If one agrees with all their assumptions and methods, the estimates of economic damage over a 20-year time horizon ranges from US$260 million to $1,361 million for fisheries, and US$332 million to $3,477 million for tourism and recreation services.

Although we may be a bit skeptical about the figures, there is no doubt that chronic mass bleaching will have a devastating effect on many communities and businesses dependent on coral reef coasts.

Research Needs

In light of all the above, where does one begin to identify priorities in research? We are all aware that many institutions and many more individuals are now focused on the bleaching issues. Because the Framework

Convention on Climate Change already provides the policy and direction with respect to global warming research and management, we will not dwell on the physical or meteorological aspects of the issues. Instead, we will touch on the biological considerations. Among the research needs, the following may be mentioned:

- The zooxanthellae story is only in outline form. At this point in the history of the science, much more research is needed to understand the physiology of these dinoflagellates, not to mention their genetic identities. However, perhaps the tools we need to sort out some of the questions have yet to be invented.
- Symbiosis and the physiological processes involved in the association and dissociation of host and symbiont are also in great need of better understanding, if we are to understand bleaching. More studies using the easy-to-handle giant clams as marine guinea pigs may prove beneficial.
- The thresholds of the stresses leading to bleaching have not yet been established, so it may be premature to announce the arrival of a pack of wolves on the coral reef. While the recent paper on differential susceptibilities of coral taxa (Marshall and Baird, 2000) is a good beginning, let us not forget that cool Magnetic Island is not the best representative of the truly tropical, coral coast, in spite of its diverse fauna.
- The mass mortalities of reef-associated organisms, coincident with bleaching, have largely been ignored, consciously or unconsciously. If we are concerned with the socioeconomic aspects of global warming, these might be as important as the bleaching events.
- The ecosystem effects are only beginning to be addressed.
- The science of ecosystem restoration and transplantation of reef organisms needs to be vigorously advanced.
- Socioeconomic studies in relation to bleaching are sorely needed, focusing on fisheries, tourism, and coastal protection.

Management Considerations

It might be pointed out that one of the institutions that took action almost immediately following the recent bleaching event is the Convention on Biological Diversity. The Secretariat organized an Expert Consultation on Coral Bleaching in Manila on 11-13 October 1999. Two groups from the Indian Ocean took early action following the 1998-1999 El Niño. These were the Coral Reef Degradation in the Indian Ocean program (CORDIO) and the Saudi National Commission for Wildlife Conservation and Development. The latter sponsored a workshop in Riyadh early this year (2000) to consider monitoring and management needs in response to the extensive coral bleaching and mortality in the Arabian and Red Sea. The Swedish International Development Cooperation Agency (Sida)-sponsored CORDIO was launched in January 1999 to study the long-term ecological and socioeconomic effects of the 1998 coral mortality. The projects in the program focus on improving remote sensing technology to detect coral bleaching, on the recovery processes of damaged reefs, and on ways of mitigating the damage, e.g., transplantation of corals and development of alternative livelihoods for affected communities (Linden and Sporrong, 1999).

Other forums have dealt with the growing issues relating to coral reefs, one of the most notable having been the Fort Lauderdale workshop. The Coral Reef Task Force of the United States might be taken as an example of a national effort to face the challenges, while the International Coral Reef Initiative (ICRI) is the broader umbrella to address management actions globally. We would be remiss if we did not mention the Global Coral Reef Monitoring Network (GCRMN) as a key player in tracking down bleaching events (Wilkinson, 2000). These various programs have addressed comprehensive challenges, one of which is coral bleaching.

Trends of the past century suggest that coral bleaching events may become more frequent and severe as the climate continues to warm, exposing coral reefs to an increasingly hostile environment (Hoegh-Guldberg, 1999). This implies that any strategy to maintain coral reefs must include reduction of greenhouse gas emissions. In principle, this particular aspect makes the phenomenon a concern to the whole international community. Thus, policy makers must initiate efforts to develop joint actions to address this issue through the United Nations system, as well as through other international programs and treaties (Pomerance, 1999; CBD, 1999). Coral reef managers and scientists should submit frequent reports on coral bleaching to their local policymakers and to their Convention delegates, expressing ongoing concern for the effects of climate change on coral reefs and other ecosystems, and calling for continued attention to the problem in international forums (Westmacott, 2000). International programs and mechanisms for financial and technical development assistance should be mobilized in order to make resources available to support implementation plans (CBD, 1999; Pomerance, 1999).

RECOMMENDATIONS

From the various workshops and authors, many recommendations have been suggested on how to address coral bleaching issues. To give the reader an idea of the range, we have attempted to make a preliminary summary of the recommendations coming from various sources in Tables 3. and 4.

Here, we are providing several recommendations for local coastal managers, from a developing country perspective:

- Build the capacity to assess and monitor coral bleaching with local personnel. Where this is not possible, establish a task force involving expertise from other towns to address local needs. Not only individuals, but institutions and programs need to be positioned to anticipate forthcoming occurrences.

[a] In order to mobilize such a task force effectively, there is a need to establish a contingency fund to call the group to action and support its monitoring activities. One approach might be to obtain commitments from local companies to contribute to a calamity fund as the need arises.

- It would be useful to understand and take precautionary measures to minimize the negative socioeconomic impacts. The local government should address the need of alternative livelihoods for coastal dwellers, in the event of economic dislocation resulting from coral bleaching. Fishers and tourism service providers may be the most directly affected. For this purpose, a contingency plan should be put in place for immedi-

Table 3. Knowledge Gaps in the Science of Coral Bleaching as Identified by Various Authors

Research needs	Authors
Pursue a better understanding of symbiosis biology:	
• Establish factors that contribute to stability or instability of coral-algal symbiosis at the cellular, algal population and individual coral levels	D'Elia et al. 1991, Glynn 1993, Goreau and Hayes 1994, 1995
• Determine the range of responses and physiological tolerances of reef-building species and their zooxanthellae and to gain some understanding of the potential for physiological and genetic adaptation	Pomerance 1999, Arceo and Quibilan (unpublished)
Determine the full ecological impact of coral bleaching on coral reef ecosystems:	
• Pursue paleoecological studies to provide estimates of long-term reef system responses to previous perturbations	D'Elia et al. 1991, Glynn 1993,
• Investigate how regional and local differences in pre-bleaching community structure affect the ecosystem response to and recovery from bleaching, including evaluations of succession and recruitment	D'Elia et al. 1991, Linden and Sporrong 1999
• Investigate methods of restoring damaged coral reef by transplantation and restoration experiments	Lindahl 1999, Goreau et al. 2000, Westmacott et al. (in press)
• Investigate effects of bleaching stressors on other coral reef species including their reproductive success and recruitment	Glynn 1993, Linden and Sporrong 1999
• Study possible continuing and secondary disturbances triggered by previous bleaching episodes	Glynn 1993
Other needs:	
• Study the impact of coral bleaching on social and economic systems, particularly for those nations whose economies are heavily dependent on the revenue generated by reef-based tourism and fisheries	CBD 1999, Linden and Sporrong 1999, Westmacott et al. (in press), URI/CRC 2000
• Develop the use of early warning systems for coral bleaching, making the products readily accessible to coral reef scientists and managers worldwide	Goreau and Hayes 1994, Pomerance 1999, CBD 1999
• Develop remote sensing as a tool to measure coral reef health	Linden and Sporrong 1999

Table 4. Recommended Priority Areas for Action from Various Sources

Global and regional levels:	Authors
Urge the UNFCCC to take all possible actions to reduce the effect of climate change	CBD 1999, Hoegh-Guldberg 1999, Pomerance 1999, Goreau et al. 2000, Westmacott et al. (in press)
Coordinate multi-disciplinary research and monitoring to document biological and meteorological variables relevant to bleaching, mortality and recovery, as well as socioeconomic parameters associated with coral reef services, and to assess the success of the management programs	CBD 1999, Pomerance 1999, Linden and Sporrong 1999, Westmacott et al. (in press)
National level:	
Invite governments and relevant bodies to submit case studies on the coral bleaching phenomenon	CBD 1999, Wilkinson1999, Linden and Sporrong 1999
Build stakeholder partnerships, community participation programmes, public education campaigns and information products that address the causes and consequences of coral bleaching	CBD 1999, Goreau and Hayes 1995, URI/CRC 2000, Arceo and Quibilan (unpublished)
Develop rapid response capability to document bleaching and mortality: training, standard survey protocols, establishment of contingency fund, or rapid release of special project funds	Goreau and Hayes 1995, CBD 1999, Pomerance 1999, URI/CRC 2000
Implement integrated marine and coastal area management plans and programmes that supplement marine and coastal protected areas to prevent the further damage of reefs	CBD 1999, Westmacott et al. (in press)
Implement urgent measures to protect the people who have lost their livelihoods because of bleaching	Wilkinson 1999, CBD 1999, Linden and Sporrong 1999, Westmacott et al. (in press)
Mobilize international programmes and mechanisms for financial and technical development assistance to support the implementation of the proposed actions	CBD 1999, Pomerance 1999

ate implementation, taking into account that there may be external emergency funds that may be tapped in times of need.

- Marine protected areas are a positive step in coral reef conservation and address not only bleaching threats but other concerns as well. Their value in addressing bleaching is indirect, but potentially significant. It is recommended that each coastal town should select and maintain a well-located protected area that will contribute to, if not guarantee, the health of the corals contained therein. Healthy corals are likely to survive an insult, such as elevated temperatures, or actual bleaching, better than previously stressed colonies. The survivors can then serve as the sources of propagules for the recolonization of damaged reefs, contributing to both numbers and diversity of recruits.
- As a general guideline, each town or region should adopt integrated coastal management as a practice to ensure the best use of marine resources.

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ASSESSING THE SOCIOECONOMIC IMPACTS OF THE CORAL BLEACHING EVENT IN THE INDIAN OCEAN

Susie Westmacott[1], Herman Cesar[2], Lida Pet Soede[3] and Olof Lindén[4]

ABSTRACT

Coastal populations in the Indian Ocean have been adversely affected by coral reef mortality resulting from the bleaching event in 1998. Assessing the socioeconomic impacts focused on the two main coastal activities in the region, tourism and fisheries. Anticipating the full impacts will be vital to enable these countries to adapt and manage the situation. The study found, in many cases, the full impacts of the reef degradation are still to be seen. The impacts are also variable across the region, as was the extent of the bleaching. Impacts on fisheries will become apparent as changes occur to the reef structure. In places where the reef structure breaks down, the reef fisheries could collapse, affecting millions of small-scale fishermen. The importance of reef fisheries in terms of provision of food and employment was established. Tourism creates both direct and indirect employment for these coastal populations and in many of these countries is an important source of foreign income. The economic costs of the coral bleaching in the Maldives was estimated at US$3 million in 1998-99, with welfare losses reaching US$63 million. Estimates of the financial cost of the bleaching in Mombasa, should dissatisfied tourists not return, was estimated at US$13-$20 million, and in Zanzibar was estimated at US$3-$5 million. Understanding and anticipating tourist behaviour will enable governments and tourism boards to take timely precautions, changing marketing strategies and retaining their tourism industry. The full socioeconomic impact of the bleaching will become apparent in the near future.

INTRODUCTION

Ever-increasing coastal populations in the Indian Ocean Region are relying on coral reefs as the basis of their livelihood. Across the region, the two common socioeconomic reef-based activities are fisheries and tourism. For local subsistence fishermen, reef fisheries often represent their only livelihood. Degradation of coral reefs will impact the reef fishery, and subsequently, the local fishing community. Tourism also, is often heavily dependent on coral reefs as the main attraction (Cesar, 2000).

The countries of the Indian Ocean vary both physically and socioeconomically. The size of a country, the area of coral reefs, the coastal population utilizing the reefs, and the wealth of the country are all indicators of pressure and dependence on reef resources, and their ability to cope with impacts such as coral bleaching. Coral Reef Degradation in the Indian Ocean (CORDIO) was initiated in response to degradation of coral reefs caused by the 1998 coral bleaching event (Linden & Sporrong, 1999). However, other factors, such as rapidly expanding coastal populations or poor planning and management, may also cause reef degradation.

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This study aims to place the 1998 bleaching in context of other threats to the reef, assess the importance of reef fisheries and reef-related tourism within the region, assess the impact of bleaching on fisheries and tourism, and estimate the overall economic impact in the Indian Ocean.

METHODS

The socioeconomic assessment included both an overall evaluation of the importance of coral reefs to the region, through the collection of national statistics on reef users (tourism and fisheries), and specific case studies to identify the impact of the coral bleaching on the users. The results of the assessments and case studies were all used to formulate the overall socioeconomic assessment of the 1998 coral reef bleaching. (Figure 1.)

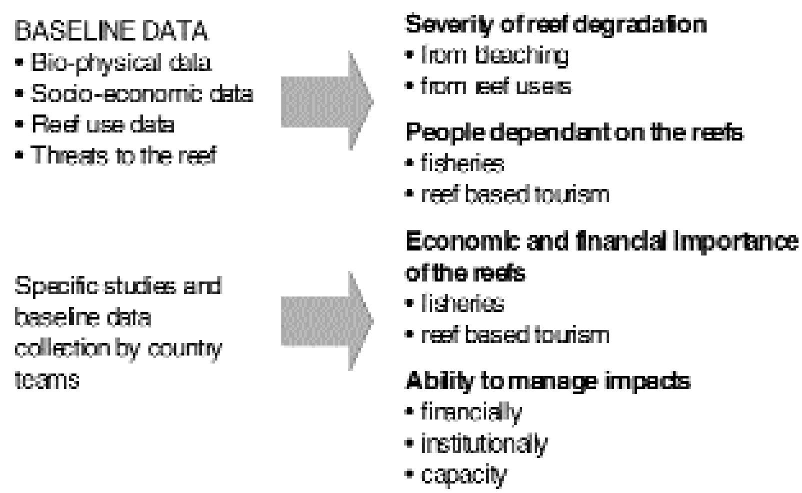


Figure 1. A series of different assessments and case studies were used to formulate the overall assessment of the impact of the bleaching on tourism & fisheries and as a whole.

RESULTS

In the Indian Ocean, the coral bleaching affected the reefs of East Africa, the Arabian Peninsula (with the exception of the northern Red Sea), the Comoros Archipelago, parts of Madagascar, the Seychelles, Southern India, Sri Lanka, the Maldives and the Chagos Archipelago. (Figure 2.) In most of these places, many corals were unable to survive the event and coral mortality ranged from 70-99 percent (Linden & Sporrong, 1999; Wilkinson et al., 1999). Recently, Bryant et al. (1998) estimated that 9,000 km^2 of coral reef in the Indian Ocean was at high risk, 10,500 km^2 at medium risk and 16,600 km^2 at low risk of degradation from coastal development, marine-based pollution, overexploitation of marine resources, and inland pollution, including sedimentation. Within the CORDIO countries, the level of risk of reef degradation ranges from low, in areas like the Chagos Archipelago where there is negligible human activity, to high, in areas such as Comoros and Mayotte, where high population growth rates are exerting increasing pressure on these reefs. (Figure 3.) Sadly, those areas least at risk from human activity and potentially in pristine condition were affected worst by the coral bleaching.

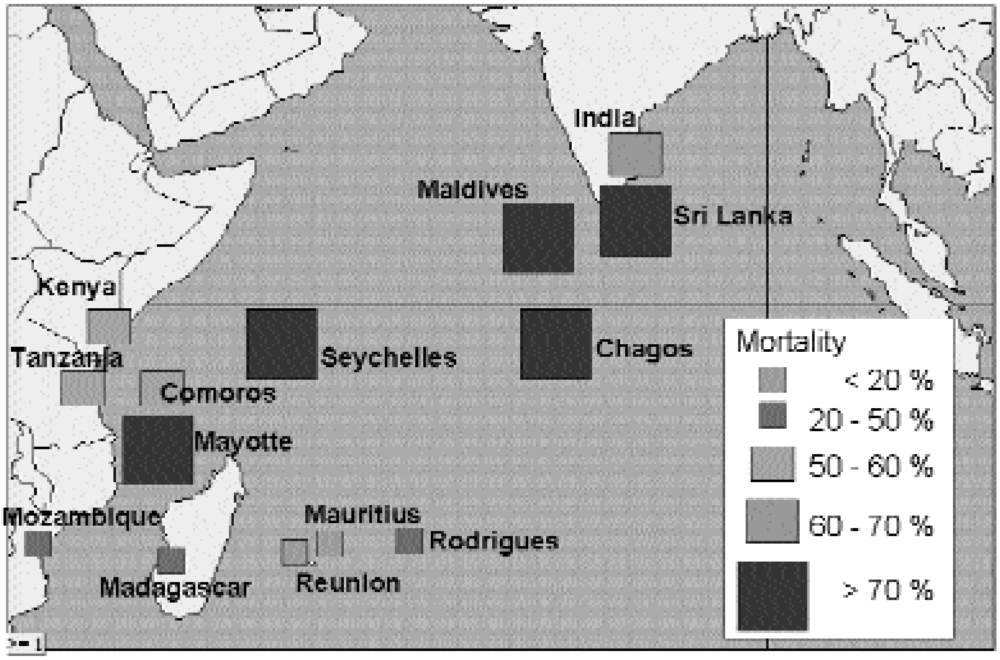


Figure 2. Coral Mortality in the Indian Ocean Resulting from the 1998 Coral Bleaching Event

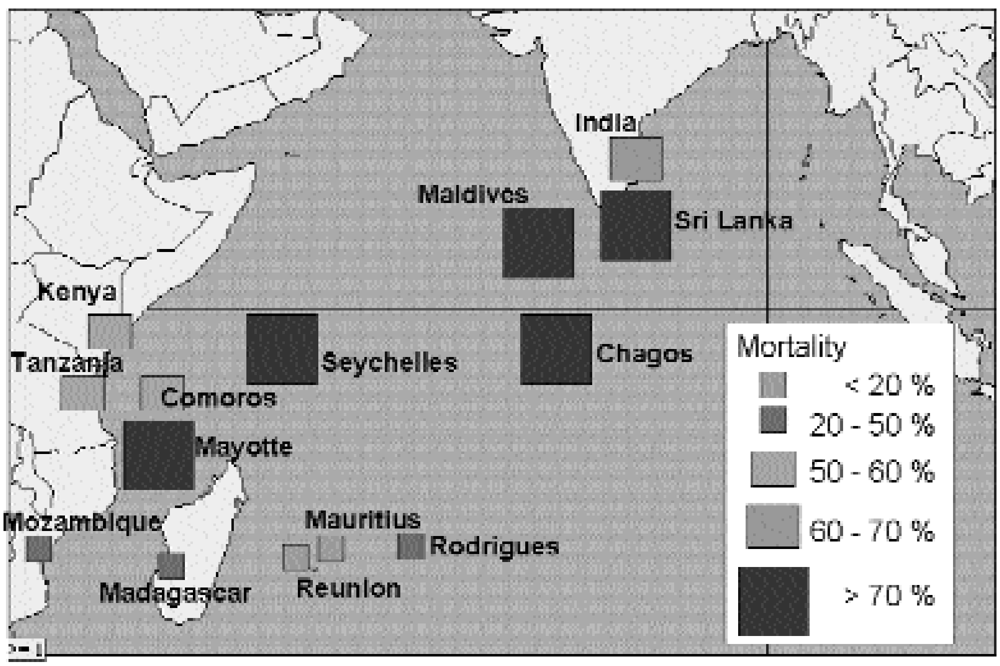


Figure 3. Reefs at Risk from Human Activities in the Indian Ocean

Table 1. Importance of Marine and Demersal Fisheries in Providing Food *(kg of fish)*, Employment *(part of overall population)*, and Foreign Earnings to Indian Ocean Countries *(++++Very high; +++High; ++Medium; +Low)*

	Food		Employment		US$	Other
Country	**Marine**	**Demersal**	**Marine**	**Demersal**		
India	++++	++++	+++	++	+	
Madagascar	+++	++++	++	+	+++	
Sri Lanka	+++	+++	+	+	-/+	Import equals export
Tanzania	++	+++		+++		
Kenya	+	++	+	+++		
Mauritius	++	++	+	++	++	Foreign fish licenses
Seychelles	+	++	+	++	+++	
Mozambique	++	+				
Maldives	+++		+++	+	+++	Baitfish supports tuna
Comoros	++		+	+++		
Rodregues	+		+	+++	+	

Potential Impacts of Coral Bleaching on Reef Fisheries

The effects of coral bleaching on reef fisheries are likely to be observed in the long term through changes in the habitat complexity. In a fishery that is entirely dependent on reef fish, catch rates may decrease and the catch composition may shift more towards the herbivorous species. These fish are often lower in value, so as a result, the economic position of fishers may deteriorate. Fisher communities that live on islands with few alternative sources of income will have difficulty sustaining their livelihoods. A fishery that targets large predatory pelagic species that forage on reef fish may also experience lower catches when these fish are forced to move to other less destroyed areas to hunt for prey. A fishery that targets small pelagic species that occupy a reef area or lagoon during certain phases of their life cycle may also experience lower catches when reefs disappear. However, when discussing the importance of reef fisheries per country, it is important to distinguish among providing food, foreign currency and employment. (Table 1.)

Case Study: The Effects of Bleaching and Coral Reef Degradation on Coral Reef Fish and Fisheries in Kenya

The Coral Reef Conservation Project (CRCP) is a U.S.-based nongovernmental organization of The Wildlife Conservation Society that has monitored Kenyan coral reefs since 1986, and fish catches associated with coral reefs since 1995. The project includes a study of fish populations in Kenya's older (>25 years), fully protected marine national parks (MNPs), Malindi and Watamu MNP; a more recently created park, Mombasa MNP (1991); and four sites with heavily fished, unprotected reefs—Vipingo, Kanamai, Ras Iwatine and Diani. Monitoring studies were conducted in late 1997 and repeated in early 1999, around four months before, and 10 months after, the coral bleaching event. For the purpose of assessing possible effects of the 1998 bleaching event, abundance and composition of the reef fish community was determined, together with biomass and composition of individual fish catches.

The underwater visual census data showed no clear changes in fish community structure that can be attributed solely to the bleaching and mortality of corals. Only the increase in abundance of surgeonfish, which are grazers that feed on algae on the surface of the dead coral, may be related to coral mortality. It appears that there is a strong relationship between management (marine park versus exploited reefs) and fish abun-

Table 2. Relative Importance of Reef based Tourism to the Economy and 5 year Trends in National Tourism for Countries of the Indian Ocean *(++++Very high; +++High; ++Medium; +Low; -Negative)*

Country	Contribution of reef-based tourism to the gross domestic product, GDP	National tourism trend
Maldives	+++++	++
Mauritius	++++	++
Comoros	+++	++
Seychelles	+++	+/
Zanzibar, Tanzania	++	+++
Madagascar	+	++
Kenya	+	+/-
India	+	+
Reunion	+	+
Sri Lanka	+	-
Mozambique	+	No data
Rodregues	No data	++++
Mayotte	No data	+++

dance for many of the studied fish families (McClanahan & Arthur, in press). The catch assessment data show a significant decline in catch between 1995 and 1999, whereas the total fishing effort, measured in numbers of fishers or boats, remained constant. There is no significant deviation from this trend after the 1998 bleaching event. Therefore, it must be concluded that at this stage, the fishery has not been significantly affected by the bleaching and mortality of corals. Nevertheless, the declining catches may be a result of overall environmental degradation. Therefore, it is expected that the effects of the recent bleaching and coral mortality may become more evident once the reefs are further eroded in the future.

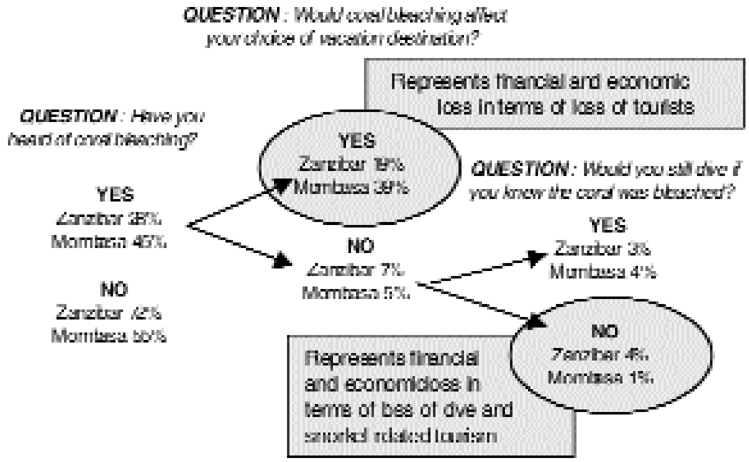
Potential Impacts of Coral Bleaching on Reef-based Tourism

The second major socioeconomic impact of the bleaching would be expected on the tourism industry. Tourism will be affected by bleaching in those areas where a substantial proportion of the industry is based on reef activities and there are few other attractions or activities for the tourists. Tourism varies throughout the countries of the Indian Ocean. The diversity of the tourism product ensures a greater or lesser dependence on the reefs. Table 2. indicates by country, the level to which tourism is dependent on reefs, as well as growth rate trends in tourism over the past five years.

Case Study: The Impacts of Coral Bleaching on Tourism in Tanzania and Kenya

One of the specific case studies, initiated as part of the socioeconomic assessment of the impacts of the coral bleaching within the CORDIO programme, was carried out in Tanzania (Zanzibar) and Kenya (Mombasa). The study found that of those who were aware of the bleaching, over 80 percent stated that knowledge that an area was bleached would affect their decision either to visit that area or to dive and snorkel in that area. (Figure 3.) However, only a limited number of tourists surveyed at the two case study sites were actually aware of coral bleaching. (Figure 4.) This low awareness could be related to their country of origin, level of interest in the marine environment or dive experience. While these links were explored, the sample size of those aware of the bleaching was too small to draw any significant conclusions. Nonetheless, survey responses do enable estimations of the financial and economic costs of the coral bleaching to be made.

In estimating the financial and economic costs of the coral bleaching, the survey techniques and the valuation methods developed by Andersson (1997) for the previous survey in Zanzibar were used. The costs are



Note: All percentages are of the total sample of divers and snorkellers

Figure 4. Responses to the Questions Regarding the Knowledge of Coral Bleaching and Its Effect on Choice of Diving Destination

Table 3. Financial and Economic Cost of the Coral Bleaching on Zanzibar and Mombasa
(Range based on assumption that 20-30% of total tourists dive.)

	Financial cost million US$	Economic cost million US$
Zanzibar	3.08- 4.62	1.88-2.82
Mombasa	13.33 19.99	10.06 15.09

based on divers' expenditure on diving, the vacation as a whole, and their stated willingness to pay. The total number of divers visiting Zanzibar is not known, so a range of 20-30 percent of the total tourists is used. These aggregated costs can be seen in Table 3.

In comparison to the 1996 data, the recreational value of the reef had not changed. This indicates that the reef remains an important component of the visit, and the value placed on having access to reef-related activities had actually increased. However, the willingness to pay for reef conservation had declines reflecting either a decline in the perceived state of the reef or a change in the type of tourists and their willingness to pay for reef conservation. Divers visiting in 1999 had significantly less experience than in 1996, which could also indicate that more experienced divers were aware of the reef conditions, and their decisions had already been affected by stories of reef degradation, or that these divers were travelling elsewhere, for more adventure and extreme diving conditions.

Case Study: The Impacts of Coral Bleaching on Tourism in the Maldives and Sri Lanka

In the Maldives, diving and other reef-related tourism are the main income-generating activity in the country, with 430,000 tourists visiting in 1999 (Ministry of Tourism, 2000). Around 45 percent of all tourists going to the Maldives were divers, with 69 percent of the divers making more than five dives. Sri Lanka has a similar number of tourists, but very few come specifically for reefs, even though they are attracted in general to the coastal areas. Approximately 8 percent were divers of whom 50 percent did only one dive. Few

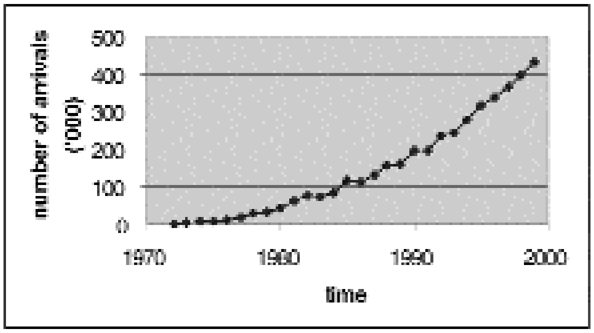


Figure 5. Annual Tourist Arrivals to Maldives Since 1972
(Source: Maldives Ministry of Tourism [1997, 2000])

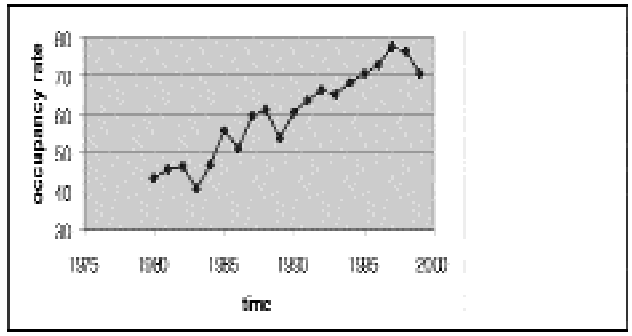


Figure 6. Annual Occupancy Rate in the Maldives Since 1980

tourists were actually aware of the bleaching. Interviews at the European airports showed that many tourists on their way to the Maldives did not know of the episode. Fifty percent of Germans surveyed had heard of the coral bleaching event in the Maldives, compared with 30 percent of the Italians and 16 percent of the Dutch. This can be explained partly by the exceptionally large media coverage in Germany and by the large percentage of divers among German tourists. At Male airport, 68 percent of departing tourists had heard of coral bleaching, while in Sri Lanka, less than one third knew of this problem.

Possible losses to the Maldives' economy were analysed based on the official tourism statistics up to December 1999. Figure 5. presents tourist arrivals since 1972. Surprisingly, there was not a significant drop in tourist arrivals in 1998-1999. In fact, tourism arrivals have increased 8 percent in both 1998 and 1999. However, trends in bed occupancy rates since 1975 give a different picture. (Figure 6.)

Given the time lag between the planning phase of expansion and the additional bed capacity, occupancy rates give a proxy for expected growth in tourism and the decrease in 1998/89 was substantial. However, the

Table 4. Losses in Tourism Revenues and Welfare in the Maldives and Sri Lanka for 1998-99

	Financial cost million US$	Economic cost million US$
Maldives	3	19
Sri Lanka	0.2	2.2

Asian crisis was also affecting tourist numbers. Another way of looking at expected growth of tourism arrivals is to check the official government tourism forecasts. In 1997, an annual growth of 10 percent was expected for the years of 1998 and 1999 (Ministry of Tourism, 1997), which was 2 percent higher than the realised figures. Here, we assume that half of this difference was due to coral bleaching. Based on this, the financial and economic losses were calculated. (Table 4.) In order to calculate these welfare losses, the surveys at Male airport focused on tourists' willingness to pay for better reef quality based on two photographs of a bleached and a non-bleached reef.

The results of the survey identified that 47 percent of the tourists considered the dead corals the most disappointing experience during their holiday, while the price of food and beverages was second, with 28 percent. This last result is interesting because nearly all resorts are based on half or full board, so that the actual amount of money spent on additional food and beverages is quite low, though beer is expensive, at around

US$5 per bottle. The interesting aspect of these responses is that they allow us to compare, and therefore scale, the willingness to pay (WTP) values. Surprisingly, the average WTP for better reef quality was not statistically different for those who found coral mortality most disappointing and those who found other parts of their holiday most disappointing. One could buy more than 50 bottles of beer for the average WTP for improved corals. This may suggest either an inconsistency in the way people respond to the various questions, or alternatively, that there are quite a few very hefty drinkers among the tourists. Unfortunately, it might also mean that many tourists do not really care about the death of coral reefs.

Overall Economic Valuation

The overall economic valuation is shown in Table 5. for an optimistic and a pessimistic scenario. The optimistic scenario is based on the assumption that the reef recovers, tourism is only marginally affected along

Table 5. Estimates of the Overall Economic Valuation of the Socioeconomic Impacts of the 1998 Coral Bleaching Event in the Indian Ocean *(Net Present Value in million US$ over a 20-year time horizon with a 10% discount rate)*

Coral Reef Ecosystem Services	Optimistic Scenario	Pessimistic Scenario
Food Production (e.g. Fisheries)	0	1361
Tourism and Recreation	494	3313
Disturbance Regulation (coastal protection)	0	2152
Other Services	114	1200
Sum Total	**608**	**8026**

the lines currently seen (2 percent), and there is no impact on the fisheries or the structure of the reef. In the pessimistic scenario, the reef structure collapses, impacting the fisheries and the coastal protection function of the reef. Tourism will also be affected. In the pessimistic scenario, the total damages over a 20-year period are over US$8 billion, primarily from coastal erosion (US$2.2 billion), tourism loss (US$3.3 billion) and fishery loss (US$1.4 billion). In the optimistic scenario described above, the losses are still considerable, but an order of magnitude less than the damages in the pessimistic scenario, stemming mainly from loss in tourism (US$0.5 billion).

Conclusions

The coral bleaching event of 1998 is already having severe ecological consequences. Much less is known about the socioeconomic impacts. Some of the worst affected areas were actually those reefs that were least at threat from other activities and were the most pristine in the region.

It can be expected, given the severity of the coral mortality following the bleaching, that the overall socioeconomic consequences are considerable, and perhaps disastrous, especially for the countries depending largely on coral reefs for their income, such as the Maldives. It is anticipated that impacts on the reef fishery will be seen in the next 2-10 years, as the reef structure breaks down. We may already be seeing impacts on tourist behaviour and their choice of destination.

The valuation of these impacts is preliminarily estimated to range from US$608 million to US$8,026 million. However, large uncertainties exist with respect to these socioeconomic consequences. Therefore, more applied research and fieldwork is needed to assess the damages to the peoples and the economies around the Indian Ocean.

ACKNOWLEDGEMENTS:

This paper is the summary of a series of studies to which many different people have contributed. It has been made possible in part with funding from the Netherlands Consultant Trust Fund at the World Bank, coordinated by Indu Hewawasam. In addition, the Swedish International Development Cooperation Agency (Sida), and WWF-Sweden have funded various vital components of the fieldwork, which has been co-ordinated by Olof Lindén. The in-country, CORDIO teams collected substantial amounts of data in support of this work. Namely, ARVAM in Reunion, Marine Parks Authority, Seychelles Fishing Authority and Shoals of Capricorn Programme in Seychelles, University of Mauritius in Mauritius, Shoals of Capricorn in Rodregues, SPEM in Mayotte, AIDE in Comoros and the University of Toliara in Madagascar. More detailed studies were possible in India with the support of Dr. Venkataraman and Mr. Rajan, and in Kenya with Tim McClanahan from CRCP. The fieldwork for the case study in Tanzania and Kenya was carried out by Irene Ngugi, supported in Zanzibar by the staff of the Institute of Marine Science, and in Mombasa by the CORDIO office. Support in the analysis of, and access to, the 1996 data was given by Jessica Andersson. The fieldwork for the Maldives case study was carried out by Ali Waheed and Marie Saleem, and by Dan Wilhelmsson in Sri Lanka. The fieldwork in the airports in Europe was carried out by Bas Rabelling and Ludovica Reina. Computational assistance was provided by Clement Roos at the IvM in the Netherlands.

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FIRST EVALUATION OF THE IMPACTS OF THE 1998 CORAL BLEACHING EVENT TO FISHERIES AND TOURISM IN THE PHILIPPINES

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ABSTRACT

This investigation is the first socioeconomic evaluation of the impact of the 1998 coral bleaching event on the fisheries and tourism industry in the Philippines that focused on case studies in Bolinao, Pangasinan, and El Nido, Bacuit Bay, Palawan. Ecological impact assessment of bleaching for these two sites reveals that indeed, bleaching caused significant changes in the reef habitat structure. Consequently, the short-term impacts on the fish community structure were to increase reef fish abundance and biomass for both sites. Impact of bleaching on tourism in El Nido was determined using survey questionnaires, key informant interviews and secondary information. Significant losses were estimated based on net revenue and welfare to the tourist industry. Assuming that these losses are permanent (i.e. at a 9 percent discount rate), damages in present value terms are roughly US$15.0 million in lost net revenues and US$14.6 million in welfare losses. Impact of bleaching on the fisheries in Bolinao was determined from secondary municipal catch data from 1996 to 2000. Also, perception surveys of fishers and a cost-benefit analysis of the fishery at the household level were undertaken. From the available data, it is concluded that impacts of the 1998 bleaching event on the fishery in Bolinao may be difficult to discern due to another more important factor, which is overfishing. Short-term trends in catch per unit of effort (CPUE) of various gears show no clear change in the year after the bleaching event, except for small-scale gill nets and fish corrals.

INTRODUCTION

Of late, widespread bleaching and other associated events coincident with the El Niño Southern Oscillation (ENSO) phenomenon have caused worldwide concern. The 1997-1998 mass bleaching event is, in fact, considered to be the worst in the 20th century (Hoegh-Guldberg, 1999; Wilkinson et al., 1999). Coinciding with high sea surface temperature (SST) anomalies, a number of countries have reported extensive coral bleaching for the first time (Wilkinson, 1998).

In the Philippines, high SST anomalies, observable through satellite data, first occurred in the South China

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Sea area, beginning in April-May 1998, and moved in a southward direction until November 1998 (NOAA/NESDIS, 2000). An initial compilation of anecdotal reports has found that the hotspot movement was accompanied by the simultaneous occurrence of coral bleaching incidents, which affected Philippine reef areas in varying degrees (Arceo et al., 2000a). Dominant reef species was one factor that appeared to influence the differential susceptibility of these reefs to bleaching. Reef areas that were known to have a dominance of Acropora (e.g., North Palawan, Tubbataha atolls) were severely affected, while in other areas (e.g. Kalayaan Island Group) the effect of bleaching was more patchy (i.e., affecting intervening colonies while not affecting others). Furthermore, the elevated SST's not only affected corals, but have also caused significant mortality in cultured giant clams (Tridacnidae) in Bolinao, Pangasinan (Gomez and Mingoa-Licuanan, 1998).

Ecological Theoretical Framework

Since the effect of bleaching is to significantly reduce live coral cover, it is expected that there will be a corresponding phase-shift in the coral community structure (Done, 1992; Karlson and Hurd, 1993; Hughes 1994). Changes in coral community structure should result in changes in the composition, abundance and biomass of associated reef fish communities. However, it remains to be documented whether or not such changes are the inevitable consequence of a bleaching disturbance.

The hypothesis that shifts in coral community structure and function may have an effect on reef fish assemblages is based on observations of changes in the trophic structure. For example, the decline in live coral cover may result in decreased abundance and biomass of obligate coral feeders such as chaetodontids (Bell and Galzin, 1984; Bouchon-Navaro and Bouchon, 1989; White, 1988). For this reason, chaetodontids or butterflyfish have been used as biological indicators of reef health, although this direct relationship has also been counter-argued (Roberts et al., 1988; Erdmann, 1997). Conversely, a significant increase in dead coral with algae or algal assemblages may result in increased grazing by echinoderms (e.g., sea urchins) and/or herbivorous fishes (see reviews by Glynn, 1990; Hixon, 1997).

Globally, initial assessments of the 1997-98 mass coral bleaching have not yet observed the expected fish community impacts described by ecological theory. For example, underwater visual census data in Kenya of bleached reefs shows no clear short-term changes in fish community structure (McClanahan & Pet-Soede, 2000), with the exception of increases in abundance of acanthurids (surgeonfish), which may be related to coral mortality, as acanthurids are grazers feeding on dead coral surfaces. Ecological bleaching results from the Philippines, particularly for El Nido, Palawan and Bolinao, Pangasinan will be briefly reported in this paper (a more comprehensive ecological assessment of the 1997-98 coral bleaching event for the Philippines can be found in Quibilan et al., 2000).

Socioeconomic Aspects

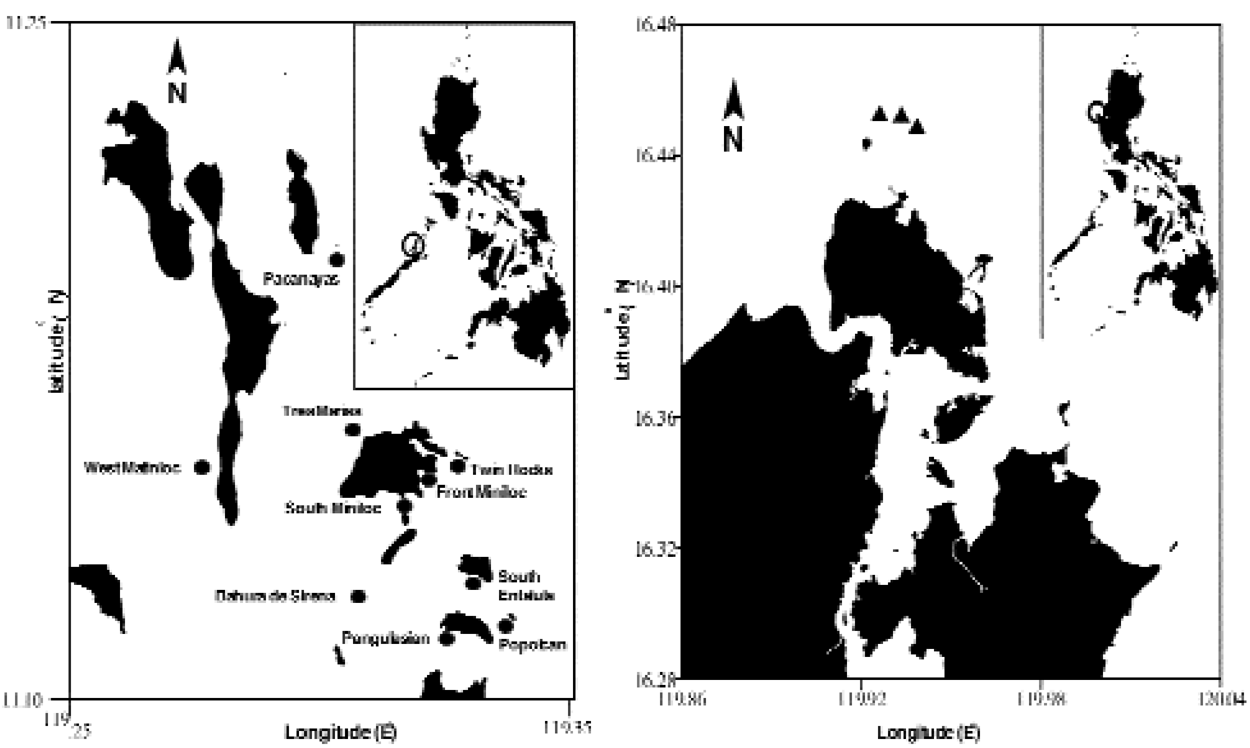
This investigation is the first socioeconomic evaluation of the impact of the 1998 coral bleaching event on the fisheries and tourism industry in the Philippines. Similar works (e.g., Wilkinson et al., 1999, Westmacott et al., 2000) have been undertaken in the Indian Ocean. While there are many possible socioeconomic implications of coral bleaching, this paper focuses on the impacts to fisheries and tourism, as these are likely to be the most important economically in the short term. In the Philippines, coral reef areas contribute 15-30 percent to the annual total fisheries production (Murdy and Ferraris, 1980; Bryant et al., 1998). It is estimated that gross municipal fisheries revenue for 1999 was 30.8 billion Pesos (roughly US$616 million) (BFAR, 1999). Tourism is an important economic sector in the Philippines, with 2.2 million arrivals in 1999 (Department of Tourism, 2000). It was estimated that the total revenues generated amounted to US$2.2 billion (DOT, 1995). Since 25 percent of the tourists engage in reef-related activities (e.g., beach holiday, SCUBA diving etc.), it can be assumed that coastal tourism comprises a major share of this total. With the recent coral bleaching event, it is possible that tourism arrivals may have declined, and/or that tourist perception may have changed in certain areas in the Philippines, affecting not only the local, but also the national economy.

Objectives

The main objective of this study is to assess the socioeconomic impact of bleaching in the Philippines, based on two case studies. The first focuses on the tourism impacts in El Nido (Bacuit Bay) on the island of Palawan, while the second focuses on the impact of bleaching on the fishery in Bolinao, Pangasinan, north-western Philippines. (Figure 1.) Both of these areas were severely affected by the 1998 mass bleaching event. Specific objectives of this study are:

- To assess the damage and susceptibility to bleaching of reefs, and also the consequent changes in associated reef fish communities' sites for both El Nido and Bolinao
- To assess and estimate the socioeconomic impact of bleaching to the tourism industry in El Nido, and

Figure1. Location of Study Areas for the Ecological and Socioeconomic Assessment Studies Undertaken in the Philippines. *Shown are the coral and reef fish survey sites for El Nido, Bacuit Bay, Palawan (n=10) (left) and Bolinao, Pangasinan (n=3) (right).*



to the fishery in Bolinao

Assessing the Ecological Impact: Corals and Reef Fishes

Study Areas

Coral and associated reef fish surveys were conducted in El Nido, Bacuit Bay, Palawan (N 11°00'-11°10'; E 119°15'-119°30') and Bolinao, Pangasinan (N 16º22'-16º27'; E 119º52'-119º59'). (Figure 1.) A total of 10 reef sites were surveyed in El Nido, surveys were conducted in March 1996 (pre-bleaching) and June 2000 (post-bleaching). Three reef sites were surveyed in Malilnep Reef, off the coast of Santiago Island, Bolinao. Reef surveys were conducted in June 1997 (pre-bleaching), June 1998 and August 1998 (during), and June 1999 (post-bleaching).

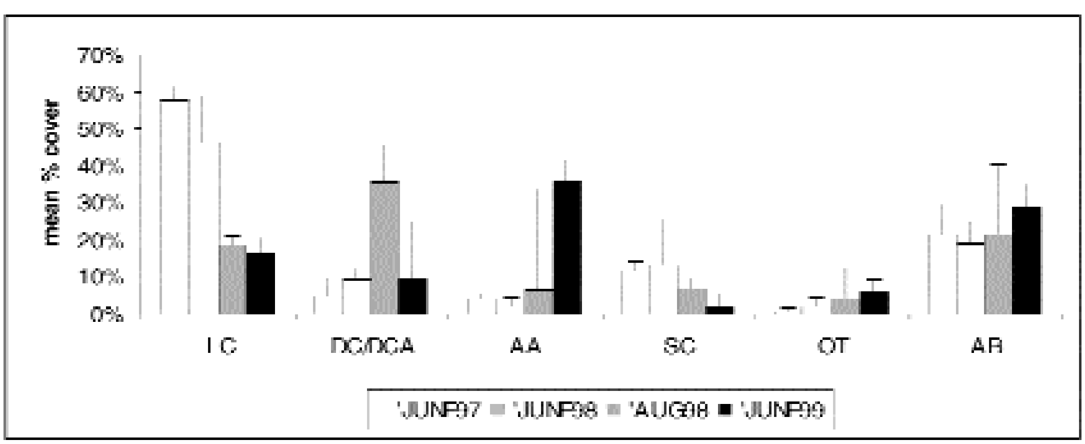
Methods

To determine changes in reef community attributes in El Nido, a total of ten 30-meter (m) transect segments were surveyed, using the life form transect intercept technique (LITT) (English et al., 1997). Data for the two years were then compared. The fish visual census technique was used to determine the abundance and sizes of reef fish species present for all 10 transects. For both the 1996 and 2000 surveys, fish censuses were made by two observers for the entire 100-m transect length. For Bolinao, underwater video transect surveys were done along a 50-m transect length, following the methods described by Osborne and Oxley (English et al., 1997). Using the same transect, associated reef fishes were surveyed using the visual fish census technique. In 1997, the underwater visual fish census was done by one observer, and in the succeeding years by two.

Results: Coral Community Structure

In El Nido, significant changes in coral community structure were evident based on comparisons of before (1996) and after (2000) bleaching reef conditions. Mean coral cover decreased by 18 percent (i.e. mean = 16 percent). Dead coral and dead coral with algae markedly decreased by 21 percent, but the abiotic components increased in cover by as much as 33 percent due to the increase in rubble. Soft coral also decreased by 4 percent but algal cover increased by as much as 10 percent. Cover of other fauna did not change from original (6 percent) compared to recent values. Average cover values for Acroporids and non-Acroporids

Figure 2. Changes in Six Major Benthic Lifeform Attibutes in 3 Reef Sites in Malilinep, Bolinao, Pangasinan from 1997 to 1999 Based on Video Surveys *Six major lifeform attributes: LC = live coral, DC/DCA = dead coral/dead coral with algae, AA= algal assemblages, SC = soft coral, OT = other flora and fauna, AB = abiotic. Bars shown are standard deviations.*



decreased by 5 percent and 14 percent respectively.

In Bolinao, live coral cover values were highest prior to the bleaching event in June 1997 (54 percent) compared to the subsequent surveys (46 percent-18 percent-17 percent). Dead coral cover was highest in August 1998 (35 percent). However the change in algal cover was more pronounced a year after the bleaching event (5 percent in August 1998 to 32 percent in June 1999). There was a decline in soft coral cover (10 percent), while no significant changes were observed for other fauna and abiotic cover. (Figure 2.)

Results: Reef Fish

In El Nido, a comparison of the total reef fish biomass before (1996) and after (2000) the bleaching event shows that biomass significantly increased in 90 percent of the sites surveyed. The post-bleaching average fish biomass is roughly three times that of 1996. (Figure 3.) This increase in biomass is true for almost all major trophic groups (herbivores, carnivores, etc.). However, the biomass of coral-feeding fishes (Labrichthyinae) evidently decreased. Species richness increased in 8 out of the 10 sites. Overall, the total number of species identified increased from 188 to 213. Herbivorous species such as Plectroglyphidodon lacrymatus and Scarus niger, which were not included among the overall dominant species in 1996, were included in the top 10 species in 2000.

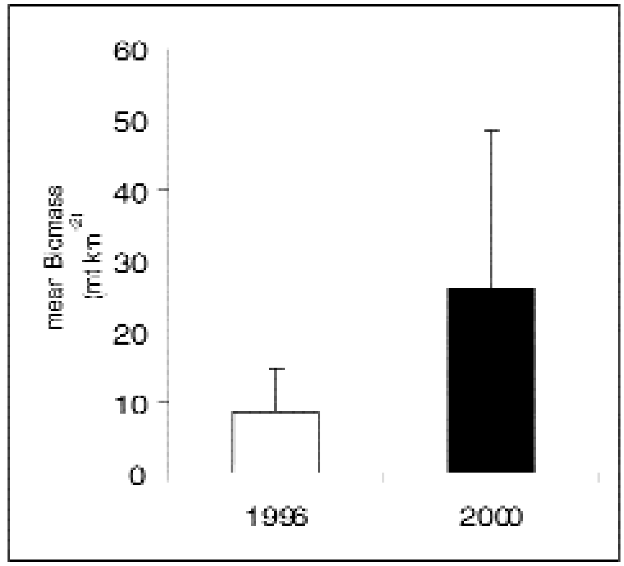


Figure 3. Mean Reef Fish Biomass (mt km^2) for All Sites in El Nido Pre- (1996) and Post- (2000) Bleaching

In Bolinao, there was a general increase in the total number of fishes from 1997 to 1999. The total number of counts did not differ significantly from one year to the next; the increase was significant between 1997 and 1999. Species belonging to the families Pomacentridae (damselfish), Acanthuridae (surgeonfish), Scaridae (parrotfish) and Pseudochromidae (dottybacks), and a sub-family of wrasses, Cheilininae and Corinae (Labridae), dominated the reef fish community. The total fish biomass (in terms of metric tons per square kilometer [mt/km^2]) also showed similar increasing trends over the three year period. It doubled from 1997 to 1999. An analysis of the biomass of the dominant species and families seen in Malilnep Reef reveals that there do not seem to be major shifts in the composition of the dominant families/subfamilies. Though most of the fish families showed increasing trends, it is interesting to note that marked increases in biomass can be seen in scarid and acanthurid species, as well as the pomacentrid, Plectroglyphidodon lacrymatus, which are all herbivores. Furthermore, distinct increases are also observed in Mullidae and the subfamily, Corinae (Labridae), which are zoobenthos feeders.

For Bolinao, all trophic groups seem to show a general increase in biomass. Only the omnivores (i.e. Balistidae, Pomacentridae, etc.) showed a significant increase. It is difficult to detect whether bleaching affected coral-feeders or corallivores (i.e. Labrichthyinae and some chaetodontids) because they are very few to begin with, and trends do not show any significant results.

ASSESSING IMPACTS OF CORAL BLEACHING ON TOURISM[6]

In the El Nido area, diving and snorkeling are the main outdoor activities of the nearly 17,000 tourists who visited the area in 1999. El Nido has two major resorts (Lagen and Miniloc), as well as two small resorts and a fair number of cottages in the town proper. El Nido is well known in the environmental economics literature for the pioneering fieldwork that Hodgson & Dixon (1988, 2000) have done there, showing the trade-off between on-land logging activities and impacted diving tourism and fisheries.

Methods

Both questionnaire surveys and secondary data sources were used in this study. Two types of surveys were carried out: (i) one for tourists in El Nido, both in town, at the resorts, and at the airport (departing tourists only); and (ii) one for key informants such as dive instructors, resort managers and cottage owners. The questionnaire was filled out by 58 tourists, in two separate weeks in the period June-September 2000. This number is relatively low, but due to the Mindanao hostage crisis, there were no more tourists present in the area during this low season period. The questionnaire was translated into German, French, Italian and Japanese. Around a dozen key informants were interviewed in the same period. The surveys of tourists asked, among other things, questions related to the willingness to pay for improvement in reef quality. Key informants' interviews were geared towards obtaining information on trends in coral cover and mortality (dive instructors) as well as tourism trends and tourist satisfaction (dive instructors, cottage owners and resort managers). The secondary data sources are the official tourism statistics of El Nido and the Province of Palawan, as well as a number of consulting reports on El Nido and Palawan. The tourism statistics were analyzed and revised based on observed severe underreporting by the cottage owners. For tax reasons, cottage owners report very low occupancy rates to the local tourism office. The real occupancy rates were calculated, using triangulation techniques, based on interviews with cottage owners.

Results

General Characteristics of Tourists in El Nido

There are two quite distinct groups of tourists in El Nido, each roughly 50 percent of the total. The first group are backpackers on a shoestring budget, typically Europeans, but also some Filipinos and other Asians. They arrive by bus or boat. They typically stay in the cottages and other lodging in El Nido proper and do some snorkeling, boat tours, nature walks, etc. in the area as part of a larger holiday in the Philippines. The other group are the resort tourists, who often fly into El Nido, and come for a luxurious diving, honeymoon or relaxation holiday. They stay either solely in El Nido or they combine this trip with diving in other parts of Palawan. (Table 1.) For both groups combined, most foreign tourists come from Europe (37 percent), followed by Japan (15 percent), South Korea (9 percent) and the USA (9 percent). Local Filipino tourists comprise a sizeable 24 percent of the total. These percentages are roughly in line with the survey sample.

[6] A detailed account of the tourism losses in economic terms in El Nido is presented in Cesar (2000).

Table 1. Number of Tourists by Country of Origin and Type of Accommodation in El Nido
1999 Data

	Europe	Japan	Korea	Philippines	USA	Others	Total
Cottages	4728	193	193	1598	675	620	**8005**
Resorts	1363	2331	1368	2413	804	328	**8607**
Total	6091	2524	1561	4011	1479	948	**16612**
% of total	37%	15%	9%	24%	9%	6%	**100%**

Tourists can also be distinguished by purpose of visit. The three main categories are:

- Divers
- Honeymooners
- General eco-tourists/vacationers.

The survey found that the daily activities of these three groups in El Nido are mostly sea-related and 47 percent of the interviewees mentioned diving as one of the activities. For most tourists, their dive was the shallow trial dive carried out on a one-to-one basis with an instructor. Only 18 percent of tourists interviewed had a diving certificate and dived more than once, while only 4 percent of tourists interviewed did more than five dives. Based on key informant interviews, it appears that the percentage of tourists that come specifically to El Nido for diving has dropped considerably over time, from over 50 percent in the late 1980s to around 10 percent currently. The reason most frequently mentioned is the deterioration of the coral reef ecosystem over recent years.

Knowledge of Marine Environment

Whether divers or not, most tourists coming to El Nido have a clear interest in the marine environment. Only 5 percent of the interviewees said they found marine life not important, while 27 percent found this rather important and 68 percent found it very important. At the same time, the general awareness of coral bleaching was found to be rather low. Only 44 percent of tourists in the sample were aware of the 1998 coral bleaching event. This is in line with results from the Maldives where a similar questionnaire was carried out in 1999 and 2000 (Cesar et al., 2000). Especially the South Koreans and Filipinos in the sample had little knowledge of coral bleaching (awareness was 31 percent and 20 percent respectively). For the South Koreans, this might be due to language problems. For the Filipinos, this number is strikingly low, given the considerable attention to the bleaching event in the media.

Losses in Tourism Revenues

To estimate the losses incurred by the tourism industry in El Nido, general trends in tourism arrivals are analyzed first. As discussed before, there are two types of tourists: (i) budget tourists staying in El Nido town; and (ii) resort guests. Though no precise data on tourism arrivals are available for the mid-eighties, it is estimated that the total number of visitors was roughly 6000, with 25 percent budget tourists and 75 percent resort tourists. Budget tourism has increased fivefold since 1985 to 8005 in 1999. This is also illustrated by the rise in the number of guest houses and cottages. In 1986 there were only three guest houses in town, while currently this number is close to 20. Resort tourism has roughly doubled since the mid-eighties to 8,607. The first four months of 2000 witnessed a considerable increase with 16 percent, partly due to strong marketing efforts by the resorts. However, due to the hostage crisis in Mindanao, tourism arrivals have dropped considerably since April 2000.

In the last few years, occupancy rates of the cottages have been close to 100 percent in the peak season and roughly 33 percent in the low season. From key informant interviews, it appears that El Niño and other types of reef degradation have not impacted budget tourist arrivals. The only loss is that fewer budget tourists than before actually dive during their stay. And those who dive make fewer dives than previously. From the roughly 20 good dive spots available in Bacuit Bay in the 1980s, less than half a dozen are worth visiting at the moment. Based on key informant interviews, this loss is estimated at 500 dives per year. Average price per dive is US$25. This loss leads to a considerable loss in profits, estimated at US$10,000 per year. At the local level, a large multiplier effect is present for additional income. Hence, we assume that losses to the local economy are double the losses in profits, or US$20,000.

At the resorts, the situation is much worse. The resorts used to cater to the exclusive high end of the dive market and Bacuit Bay was advertised as a pristine diving area. Over recent years, it has lost this image, due to the degradation of its reefs. According to key informants, this degradation is the result of the following five factors ranked according to perceived importance:

- Coral bleaching (El Niño)
- 1998 typhoon (also linked to El Niño)
- Destructive fishing practices
- General overfishing
- Tourism damage (anchoring; trampling on reefs by divers and snorkelers; etc.)

In the mid-1980s, most resort guests were divers. Currently, the percentage of real divers is estimated at roughly 10 percent, based on our sample and key informant interviews. The resorts have shifted in the meantime towards other market segments, such as honeymooners. More than half of the tourists visiting the luxury Miniloc resort were Korean and Japanese honeymooners, who typically came for a 3-4 day visit. Nevertheless, the low occupancy rates suggest that the “lost” divers are a true loss to the resorts. We estimate that the true loss is roughly 4,000 guests per year with a loss in net revenue of US$2 million. As most of the labor is local, and a considerable amount of other expenses are also incurred within the Philippines, we assume a multiplier effect of 50 percent (Cesar, 1996), bringing the total annual losses to US$3 million.

Whether the tourism loss is temporary or permanent remains to be seen. Here, two scenarios are worked out. In one, the losses are temporary and gradually disappear over a ten year period, concurrent with coral recovery. A second scenario assumes no significant recovery of the ecosystem and the losses are permanent. The net present value of the losses is calculated with two discount rates, a low one of 3 percent and a high one of 9 percent per year. It is not clear which part of the losses are due to the 1998 El Niño event, as the trends had started beforehand, as observed by Hodgson & Dixon (2000). At the same time, key informants indicated that the 1998 El Niño event (through coral bleaching), and the typhoon, were the two major causes of reef degradation in the last decade. We therefore assume that 50 percent of the losses are attributable to El Niño, or US$1.5 million for the resorts and US$10,000 for the local dive industry. The results are presented in Table 2. Total losses of value added in present value terms would be between US$15 and $27 million depending on

Table 2. Loss in Net Revenue to the Philippine Economy Due to Coral Bleaching in El Nido
In Net Present Value (NPV) In '000 US$ Over The Period 2000-2025

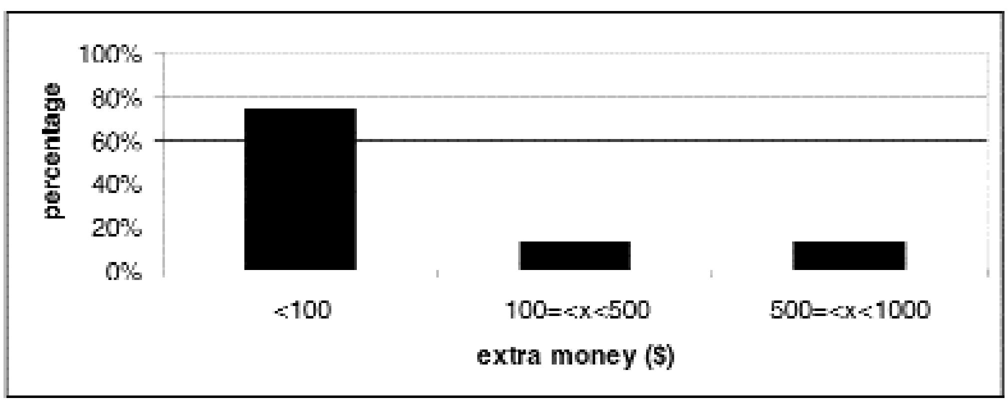
	Annual Loss to Local Economy	NPV Permanent *3% discount rate*	NPV Permanent *9% discount rate*	NPV Temporary *3% discount rate*	NPV Temporary *9% discount rate*
Budget tourists	10	179	99	49	40
Resort tourists	1500	26,815	14,893	7,349	5971
Total losses	1510	26,994	14,992	7398	6010

the discount rate. If the losses are temporary, the totals would drop to US$6.0 to $7.4 million.

Welfare Losses from Divers

Besides financial losses to the local economies, coral bleaching can also affect tourists' holiday satisfaction and thereby create a loss in their welfare. In order to calculate these welfare losses, the surveys in El Nido focused on tourists' willingness to pay for better reef quality. For this reason, two pictures were shown. The first picture shows a reef with greatly reduced live coral cover (current situation). The second picture represents a reef with high live coral cover (pre-bleaching situation). Fish abundance is the same in both pictures. The specific question was how much tourists were willing to pay extra to go to hypothetical remote areas on Palawan where reefs were not affected by coral bleaching and which were, in all other respects, the same. Figure 4. shows the distribution of this willingness to pay (WTP) with a mean number of US$88.5. Divers were prepared to pay considerably more than snorkelers: the mean WTP for divers was US$202, and for

Figure 4. Willingness to Pay for Better Reef Quality in Bacuit Bay (El Nido)



snorkelers, US$26.

This individual WTP (Figure 4.) corresponds with a total WTP of US$1.5 million per year. To estimate the net present value of the WTP over time, we assume, as before, two scenarios, one with permanent reef deterioration and one with a temporary decline. Both scenarios use a discount rate of 3 percent and 9 percent. The results are

Table 3. Total Loss in Welfare of Tourists Due to Coral Bleaching in El Nido
In Net Present Value (NPV) in '000 US$ over the period 2000-2025

	WTP per individual	Annual Loss in Welfare	NPV Permanent	NPV Permanent	NPV Temporary	NPV Temporary
	US$		*3% discount rate*	*9% discount rate*	*3% discount rate*	*9% discount rate*
Divers	*US$ 202*	1,191	21,288	11,823	5,834	4,740
Snorkellers	*US$ 26*	278	4,976	2,764	1,364	1,108
Total losses	US$ 88.5	1,469	26,263	14,587	7,198	5,848

presented in Table 3.

Assessing Impacts of Coral Bleaching on Fisheries

Methods

Catch and effort data collected since 1996 by the Marine Fisheries Resources Management Project (MFRMP) were used to study trends in total catch and catch per unit effort (CPUE) to see if there were significant changes in the trends after 1998 that could be related to the bleaching event. Also, perceptions of fishers were inventoried on causes of changes in their fishery and on the importance of bleaching. Finally, literature, interviews and distributed catch logbooks were used in a cost-benefit analysis of the fishery at the household level, and to calculate the socioeconomic effects of bleaching if any. For the cost-benefit analysis of the fishery at individual household levels, a simple formula was used. The annual net revenue of a certain type of fishery i, NR_i, was calculated by subtracting the operational costs, C_{oi}, and the opportunity costs of labor, C_l, from the total gross revenues of this type of fishing, GR_i: $NR_i = GR_i - (C_{oi} + C_l)$. The gross revenue per fisher, GR_I, was a combination of the total annual catch biomass (kg) per fish category per fisher and the average price for the fish caught (per kg). To estimate GR_I, the average daily catch was estimated for each gear from interviews and logbooks. The average price paid to fishers at the island was taken from interviews and observations. The opportunity cost of labor for unskilled personnel was estimated from interviews at 120-180 Pesos/day or a midpoint estimate of US$75 per month. The average monthly costs for the boat were added to the average costs for the gear to calculate operational costs per month, or per trip, for different fishing gears. The total operational costs were added to the opportunity costs for labor and deducted from the gross revenue.

Results

Short-term Trends in Catch Rates: 1996-1998

An estimated total of 3,154 fishers are engaged in the fishery at and around the Bolinao reef area (200 km^2) (Anonymous, 1998). A large variety of fishing gear is used, and patterns in resource utilisation vary with different requirements for operation of the gear and differences in target species. Of the reef fishery gears, large-scale spear guns, using compressors, catch the most, followed by triplet nets. (Table 4.) The parisris (a type of gillnet) and deep-sea hook and line (h&l) are most efficient, catching some 6-8 kg of fish per hour (kg/hr). Lowest catch rates of 0.25-1 kg/hr are found for gillnets that are operated during the day, small-scale spear guns, and hook and line. Logbooks confirm these average catches and show, by large daily variances

Table 4. Average Daily Catch per Fisher for the Most Common Fishing Gears in Bolinao, Based on Interviews and Logbooks

gear	hrs	daily catch (kg)	logbook catch (kg)	maximum (kg)	minimum (kg)	major category	catch/hr (kg)
Deepsea h&l	12	75		200	20	tuna, mackerel	6.25
Lamp net large	12	50		500	0	anchovy, squid	4.17
Purisris	4	30	28.8-34.1	200	0	houndsfish	7.50
Compressor	8	30		40	20	lobster, grouper	3.75
Shell compressor	6	20		25	15	nylonshells	3.33
Triplet	8	15	30	20	10	emperor, parrot	1.88
Fixed trap	0.5	10	3.2	17	3	rabbitfish, mixed	20.00
Gleaning	4	7		15	5	shells	1.75
Gillnet	8	7	3.4-8.5	10	5	rabbitfish, ponyfish	0.88
H&L	12	5	2.5-6.9	8	1	grouper, mixed	0.42
Crab pot	3	5		8	0	crab	1.67
Spear gun small	9	4	1.5	6	1	rabbitfish, squid	0.44
Aquarium	5	50*		100*	20*	butterflyfish	10.00*

* Note that this is not in kg but in numbers of fish caught.

around the average catches, the uncertainty of the fisheries.

When studying the catch rates between years, there appears little difference between catch rates in 1997 (before bleaching) and in 1999 (after bleaching) for most fishing gear. Only catch rates for tabar or lambat, a shallow water gill net operated while pounding on the water surface, are clearly higher than before 1999. These fishers aim mostly at herbivores such as rabbitfish and parrotfish. Even when accounting for the level of fishing effort, again, only tabar nets show a significant increase in CPUE at an even slightly higher level of

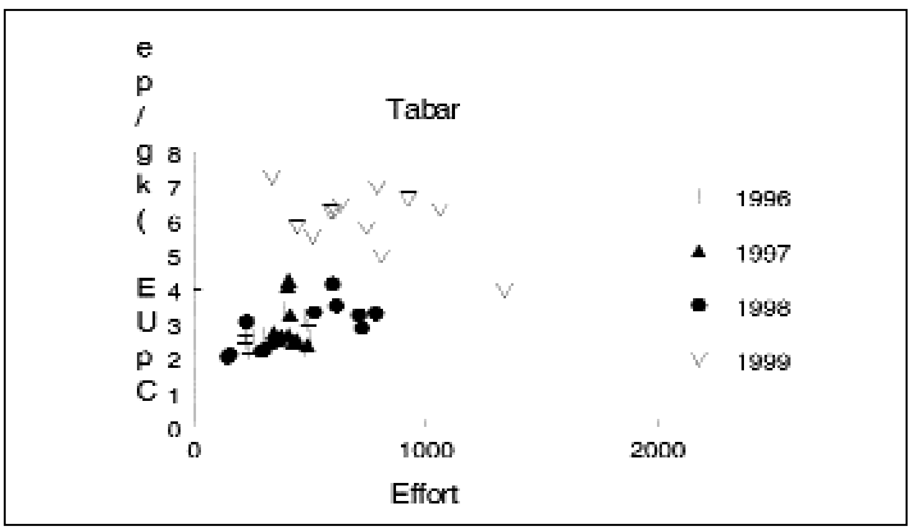
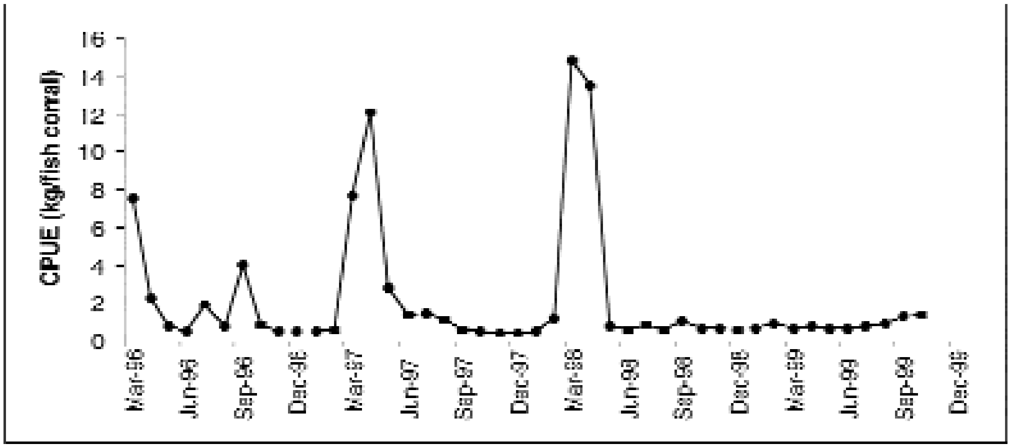


Figure 5. Effort and CPUE for *Tabar (gill-net operated while pounding on the water surface to scare fish)* from 1996-1999

fishing effort. (Figure 5.) Thus it appears that only this fishery benefited from changes that occurred in 1998.

This could be related to the bleaching event; nevertheless from the underwater visual census data we cannot find sufficient arguments for particular shifts in the fish community that would only affect this particular

Figure 6. Trends in Catch-Per-Unit Effort (CPUE) of Fish Corrals That Target Rabbitfishes (Family Siganidae) from March 1996-November 1999 in Bolinao, Pangasinan
Highest peaks in rabbitfish catches are observed from March-June, except in 1999, a year after the bleaching event (see also Pastor et al., 2000).



fishery. When asked, most of the gill net fishers actually said that their catches had reduced over the past years; no one mentioned increasing catches.

Recruitment Failure of Rabbitfish in Bolinao

A relatively short-term, indirect impact of bleaching may be shown using catch data derived from fish corrals, from 1996 to 1999. Fish corrals are deployed on the reef and contribute 10 percent to the total fishery in Bolinao. The majority of the fish caught using this gear are rabbitfish. The annual peak observed is between March and June. This annual peak coincides with what the locals call the barangen (rabbitfish) runs. Schools of juvenile rabbitfish enter the reef consistently, year after year, thereby supporting a thriving siganid fishery. Concession areas for the placement of fish corrals are bid for yearly and facilitated by the local government of Bolinao. The data shows that a year after the bleaching event in Bolinao (June 1998), there was no peak in rabbitfish catches compared to the previous years. (Figure 6.)

Perception of Fishers on Bleaching

From the interviews we found that 57 percent of the fishers had heard about bleaching and 53 percent had witnessed it personally. Of the people who had heard about or had witnessed the bleaching, 79 percent said that it was caused by the use of sodium cyanide in the illegal fishery for aquarium and live food fish. Only 21 percent said that El Niño caused it, and most of these had probably heard the correct explanation of the phenomenon during community consultation meetings. Some thought that it caused catches to drop.

When asked about their catches, 90 percent of the fishers said that the catch biomass had changed since five years ago. Eight percent said there are more fish now as a result of better management (stricter enforcement of the ban on destructive fishing) and 89 percent said that the catches had gone down, mostly because of overfishing (64 percent) and destructive fishing (14 percent). Of all fishers, 33 percent said that size in the catch has also changed, and is smaller (82 percent) or larger (18 percent) than 5 years ago. Of all fishers interviewed, 43 percent said that the species composition has changed, and that some species, such as cardinalfish, cannot be caught anymore. Most fishers (37 percent) suggested that strict enforcement of the recently established fishery ordinance was the best solution.

Cost-benefit Analyses of the Fishery

The average monthly income in 1985 for small-scale Bolinao fishers was estimated at some 470 Pesos (US$9.4) per month, with household expenditures almost doubling the income; it was concluded that fishing does not support minimum financial needs for survival (McManus and Thia-Eng 1990). At present however, it appears that each fisher is able to feed his family and save some money for other expenses. Prices vary at the different points in the product chain and increase sometimes as much as 300 percent, from one level to the next. The cost of operation varies among fisheries, with highest total costs for larger boats, and for the use of expensive technology. When we use our estimates for revenue and costs, average gross income for the different fisheries varied from US$125–$300. (Table 5.) For an estimate of the added value of a fishery, the opportunity costs of labor are deducted. The result shows that, except for shell collectors, who would not consider another occupation, as they are mostly women and children, every fishing operation makes significantly more money than work as an unskilled laborer. Net incomes after deducting opportunity costs of labor vary between 680-8,840 Pesos (US$17-$221) per month. Especially the larger scale operations, even after dividing the income among crewmembers, have significant monthly incomes. Fishers using crab pots and lagrite (encircling net operated at night with lamps) have lowest net incomes, but these fishers often have

Table 5. Estimate of Average Net Income in US$ per Fishing Operation per Month for Different Gear Types *(1 US$ = 40 P)*

Gear type	Operational costs	Opportunity costs labour	Gross revenue	Net income per month (US$)
Nylon shell collector	438 (437.5)	75	3750	3312[1]
Speargun - large-scale	165(164.9)	75	2625	2460[1]
Basnig	265 (264.9)	75	1600	1335[1]
Hook and line - deepsea	139 (138.85)	75	1410	1271[1]
Parisris	187 (187.4)	75	600	413[1]
Fixed traps	4 (3.9)	75	300	221
Triplet nets	58 (58.1)	75	300	167
Gillnets	26 (26.1)	75	260	159
Fry collector	-	75	187.50	112.5[2]
Hook and line - nighttime	27 (27.1)	75	160	58
Hook and line - daytime	41 (41.1)	75	160	44
Speargun - small-scale	35 (34.9)	75	140	30
Lagrite	33 (32.9)	75	125	17[2]
Crab pots	30 (29.8)	75	125	20
Shell collector	-	75	10	-65[3]

[1]Note that this is the net income of the boat; a sharing system is applied to divide this to crewmembers. [2]Note that this is a seasonal extra activity. [3]Note that this is performed by women and children, for whom there is no need to calculate opportunity costs of labour, so net income is actually US$10 per month.

other (fishery) sources of income.

Discussion

Ecological Impacts

For both cases, El Nido and Bolinao, the changes in the reef habitat structure (decline in coral cover vis-à-vis increase in algae) can be attributed to the bleaching event. However, the changes in the fish community structure cannot be so easily explained. The short-term effect is that fish abundance and biomass increased for both sites, primarily due to the increase in herbivores. Similar observations were reported in Ishigaki, Japan (Shibuno et al., 1999). It is possible that such increases may be attributed to the sudden increase in available food resources (algae) and/or it might be just a case of good recruitment prior to a bleaching event.

Tourism and Impact of Coral Bleaching

As the quality of reefs in El Nido has continually deteriorated in the last 10 years, the image of El Nido as a prime diving destination is threatened. Our study showed that indeed, the mass bleaching event and the passage of a storm in 1998 (also El Niño-related) has significantly aggravated the reef condition in El Nido. Since the majority of the tourists have a keen interest in the marine environment and, in particular, engage in reef-related activities (e.g., diving and snorkeling), it is clear that there are significant losses, based on net revenue and welfare to the tourist industry in El Nido. Assuming that these losses are permanent, and using a 9 percent discount rate, damages in present value terms are roughly US$15.0 million in lost net revenues and US$14.6 million in welfare losses.

Decoupling the Effects of Overfishing and the Impact of Coral Bleaching

Short-term trends in catches show no clear change in the year after the bleaching, except for catches with the small-scale gill net called tabar, and fish corrals. Only if the 100 percent increase in catches of tabar fishers is indeed related to the bleaching, could it be argued that the bleaching affected their income positively. None of the fishers that use this gear mentioned this increase, however. Based on 10-year CPUE data (1988-1993; 1996-1999) of various fishing gears that were monitored in Bolinao (Pastor et al., 2000), trends derived were so variable that it was difficult to discern whether bleaching had a direct impact on the fishery. The difficulty in detecting the impact of bleaching on the fishery may have been due to factors such as overfishing and the nature of the fishery (e.g., multi-gear, seasonality, variable deployment and use of fishing gears).

Westmacott et al. (2000) hypothesized that the potential impacts of coral bleaching on reef fisheries may be reflected in the subsequent decrease in catch rates and/or changes in catch composition towards herbivorous species that are less economically important. They cautioned that these projections are based on the basic assumption that the impact of coral bleaching on reef fisheries is observed in the long-term through changes in habitat complexity. The projections maybe true, but the assumptions should include that areas studied are not overfished. Our experience in Bolinao, even with long-term data sets, will show that it will be very difficult to detect the bleaching impact if the majority of fishes caught were herbivores in the first place. Given that herbivores are the dominant catch for a particular area, in this case, Bolinao, it is best to provide evidence of how shifts within this trophic group may be demonstrated.

Current data appears to indicate little impact from the 1998 bleaching event on the fishery of Balinao. Careless publication of such a conclusion can have serious implications, especially when this conclusion is used to downplay the seriousness of bleaching. It was never intended to provide material for such use; however, with the current data, it remains to be seen whether the adaptive nature of fishers (i.e. to compensate for their daily needs) can sustain their socioeconomic position in the long-term. This could be caused by insufficient data, as some will argue; however, based on ecological evidence, the resilience of these reef communities vis-à-vis the fishery is jeopardised through the slow recovery of the coral community and shifts in the associated fish assemblages (Arceo et al., 2000b; Dantis et al., 2000).

It may be that it will take longer before the fishery indeed experiences changes that are causally related to the 1998 bleaching event. Similar conclusions were drawn for the Kenyan coastal fishery from Mombasa (McClanahan and Pet-Soede, 2000). Within the ongoing work of the research and management projects in Bolinao, this is likely to surface, but it will remain difficult to relate such changes to the bleaching only. It appears that so far the fishers in Bolinao are quite able to sustain their livelihoods, even in a fishery that is ecologically poor, in that it exploits mostly the lowest trophic groups and has few alternative fishing stocks left to turn to. However, they also have little possibility of setting aside money for large investments. This means that they are stuck in the current situation. If, indeed, the fishery collapses in the future, as a result of delayed bleaching effects, or other factors that are supposed to influence the fishery performance, such as overfishing, deteriorating water quality and habitat conditions, there is little else for the fishers to do but look for income in an entirely different sector.

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THE VALUE OF DIVE-TOURISM AND THE IMPACTS OF CORAL BLEACHING ON DIVING IN PALAU[1]

Tom Graham[2], Noah Idechong[3], Kristin Sherwood[4]

ABSTRACT

Dive tourism is the most important industry in the small island nation of Palau, Micronesia. In the latter half of the 1990s about 50,000 scuba divers and snorkelers (together called divers) visited Palau each year, generating substantial benefits for the local economy and for themselves. An assessment of the magnitude of some of these benefits, and how they were impacted by a mass coral bleaching event in 1998, was accomplished through interviews with 100 visiting divers in each of the years 1997 and 2000.

Contingent valuation questions, using a hypothetical permit fee as a proxy for net value, were used to estimate the consumer surplus that accrued to visiting divers. In 2000 the average individual willingness to pay for such a permit was US$32. With about 50,000 divers visiting Palau each year, this suggests a total consumer surplus of about US$1.5 million per year.

The impacts of the 1998 bleaching event, which resulted in the death of at least half the live hard coral cover at most of Palau's popular dive sites, were examined through analysis of tourist visitation patterns, comparisons of diver satisfaction before (1997) and after (2000) the bleaching event, and analysis of the relationships between satisfaction and individual consumer surplus. It was found that the bleaching event resulted in detectable, but not dramatic, impacts on the net value of dive-tourism in Palau. The number of tourists visiting in 1999 was probably as much as 5 percent, and possibly as much as 10 percent, less than it would have been without the bleaching event, with proportional impacts on both consumer surplus and producer surplus. The average individual surplus enjoyed by visiting divers appears also to have been impacted, but probably by no more than 10 percent. The combined effects of lost visitation and reduced satisfaction, therefore, may have caused negative impacts to total producer surplus of as much as 10 percent, and to total consumer surplus of as much as 20 percent (i.e. roughly US$350,000/year), in the two years following the bleaching event.

BACKGROUND

The Republic of Palau in western Micronesia is a country of about 20,000 people. Tourism is the most important economic sector. Local spending by foreign tourists, for example, was estimated to be about

[1]This study was performed by the Palau Conservation Society (PO Box 1811, Koror, PW 96940, Palau; PCS@palaunet.com) with funding from the Keidanren Nature Conservation Fund, Japan, and the David and Lucile Packard Foundation, USA.

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US$67 million in 1996, equal to about 47 percent of gross domestic product (Bank of Hawaii, 2000).[5] The visitation rate peaked in 1997 at 64,000 tourists per year, having increased from only about 4,000 in the early 1980s. The main tourism markets are Japan, the USA, and in only the last five years, Taiwan. About half of Palau's tourists visit with the primary purpose of scuba diving. Most of the remainder can be considered general interest tourists, but virtually all of them engage in marine recreational activities, including snorkeling, motorboat touring, kayaking, and fishing. An area in the southern part of the country's main archipelago, known as the Rock Islands or southern lagoon, is where most marine tourist activity takes place. (See map in Figure 1.)

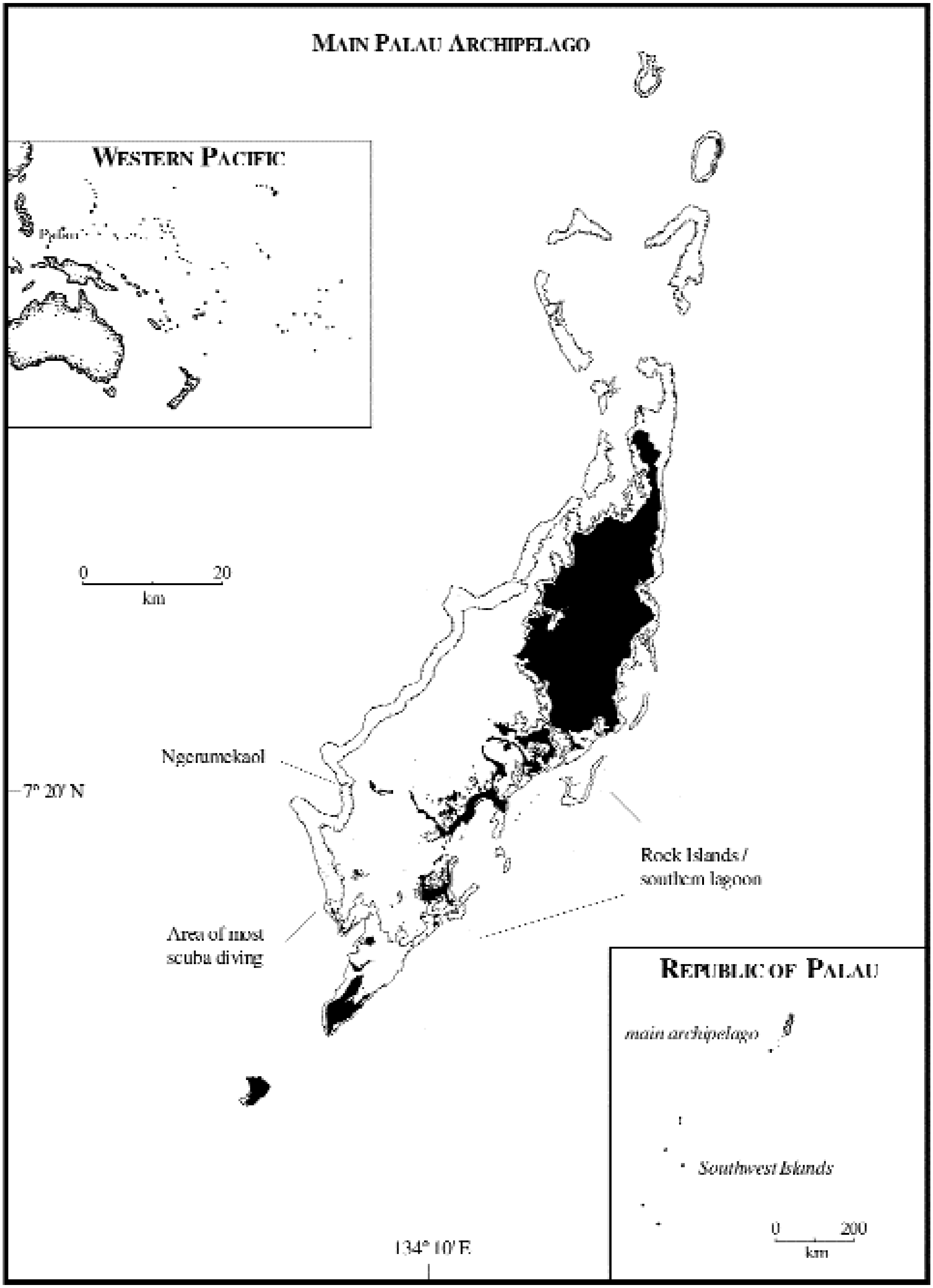
The Rock Islands themselves, numbering about 400, are steep-sided karstic limestone islands scattered through the shallow southern lagoon. With their secluded beaches, protected waters, and numerous fringing and patch coral reefs, the Rock Islands are the main attraction for non-scuba diving tourists. They also provide a popular recreation area for residents. The southern lagoon is about 800 square kilometers (km^2) in size and is bounded on most sides by a barrier reef, on which most scuba diving takes place. A short stretch of this reef on the southwest side, little more than 10 kilometers (km) long, and dominated on the outside by steep walls, receives more than half of the scuba dives made in Palau. Some of the dive sites along this stretch of reef are world-renowned and contribute to Palau's reputation as one of the world's best scuba dive destinations.

This paper reports on the results of a study initiated in 1997. Using systematic interviews with local tour operators, dive guides, and visiting divers,[6] the objectives were to describe visitation and activity patterns, assess visitor satisfaction, identify changes in the marine environment—particularly at dive sites—and identify problems in the dive industry.

After completing a set of interviews in 1997, two important events occurred. In late 1997, the economies of many Asian countries virtually collapsed. About the same time, the first effects of the 1997-1998 El Niño Southern Oscillation (ENSO) event were being felt in Palau in the form of a drought. By late 1998, the climate and oceans had swung from El Niño to La Niña conditions, with elevated sea levels, and more critically, elevated sea surface temperatures that resulted in, or contributed to, the bleaching of a large number of hard and soft corals on Palau's reefs. A study in November 1998, limited to the southern half of Palau's main archipelago, found 63 percent of scleractinian colonies bleached (Bruno et al., in prep.). By early 1999 most affected corals had either recovered or died. Mortality to corals varied widely by area, habitat, and taxa, but the post-bleaching conditions at one popular dive site, Ngerumekaol, on the southwest barrier reef, are probably indicative of what visiting scuba divers encountered in 1999 and 2000. Live hard coral cover was found to be about 25 percent and recent-dead coral cover about 35 percent, implying a loss of slightly more than half of the formerly live cover (Golbuu et al., 1999).

[5]Government is also an important sector, with about 40 percent of its revenues coming from foreign grants (Bank of Hawaii, 2000), primarily from the US through the Compact of Free Association that has governed relations between the two countries since Palau's independence in 1994.

[6]The term diver refers here to both scuba divers and snorkelers, and since virtually all tourists to Palau engage in at least one of these two activities, virtually all can be considered divers. Survey respondents were classified as being either scuba divers or snorkelers according to which they considered to be their primary diving activity.


MAIN PALAU ARCHIPELAGO
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Ngerumekaol
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scuba diving
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Southwest Islands
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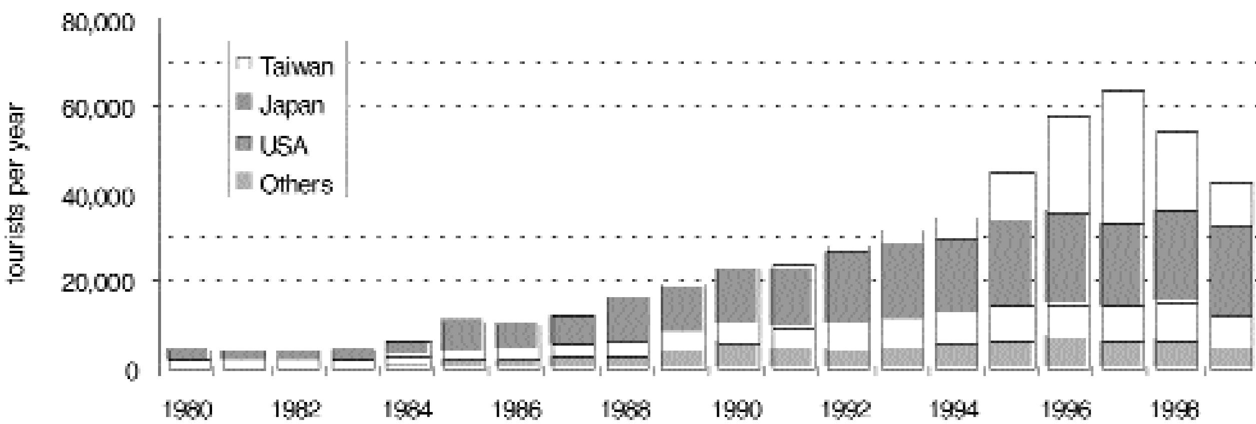
In mid-2000, the survey of visiting divers was repeated, but with the added objectives of assessing the value of diving to divers (translating satisfaction to value) and assessing the impacts of the coral bleaching event on satisfaction and value. The results presented here are limited to those two objectives and are based only on the surveys of visiting divers, not on the surveys of local tour operators and dive guides.[7]

VISITATION PATTERNS

Figure 2. shows the number of tourists, by nationality, visiting Palau each year from 1980 through 1999. It can be seen that the especially rapid increase in visitation from 1994 through 1997, and the subsequent rapid decline, were mostly due to dramatic changes in the Taiwanese market segment. The beginning of the boom was coincident with the establishment in 1994 of direct flights between Taiwan and Palau, and the downturn was coincident with the beginning of the Asian economic crisis. Although Taiwan weathered the crisis relatively unscathed, the weakening of other Asian currencies made Asian vacation destinations such as Indonesia and Thailand more attractive relative to Palau, with its US currency.

Figure 2. Tourist Arrivals to Palau



Because of the nearly coincidental occurrence of the Asian economic crisis and the coral bleaching event, it is difficult to distinguish the effects of the two on visitation to Palau. Any impacts of the bleaching event would have been felt first in 1999, and indeed, the decrease in visitation from 1998 to 1999 was greater than the previous year's decrease. Most of the decrease was in the Taiwanese market. There was no change in visitation from Japan,[8] a 16 percent decrease in visitation from the US, and a 26 percent decrease from other nations, including Europe and other Asian countries. Like the Taiwanese segment, the decreases for all other nationalities (or lack of increases) were probably due at least in part to alternative vacation destinations in Asia having become increasingly less expensive relative to Palau. However, anecdotal information from dive operators in Palau who catered to US and European visitors suggests that the bleaching event also had an impact, if not a great one. These operators received numerous inquiries from prospective customers about

[7]See PCS (in prep.) for a full report of the study.

[8]Given that the Japanese economy was strongly impacted by the financial crisis, it is noteworthy that visitation from Japan remained steady through the crisis—it suggests that Palau's share of Japan's tourist market is a relatively "high-end" segment and relatively invulnerable to volatility in the Japanese economy.

the impacts of the bleaching event on the condition of the reefs and the quality of diving. A few of the visiting divers interviewed in this study said that had they known about the effects of the bleaching event, they would not have visited. In summary, it appears that visitation in 1999 was substantially, but not dramatically, negatively impacted by the coral bleaching event. It seems reasonable to conclude that the number of tourists in 1999 was probably as much as 5 percent, and possibly as much as 10 percent, lower than it would have been had there been no coral bleaching event.

THE VALUE OF DIVING

Like coral reefs in general, the coral reefs of Palau provide value—both to local residents and to the world—through many uses and services, including food production, recreation, and biodiversity. A source of value that is especially important in Palau's case is tourism, as Palau's coral reefs are clearly the foundation of the country's tourism industry, which is the mainstay of its economy.

The net economic value of a resource or an enterprise based on that resource can be defined as the sum of producer surplus and consumer surplus. Producer surplus is the net value that accrues to the producers (essentially profits, if purely a private sector enterprise). In the case of Palau's tourism industry, the producers include the business participants in the industry, as well as the Palauan public, which owns and controls access to the natural resources that support the industry. Consumer surplus is the net value that accrues to the consumers—in this case, visiting divers. The net value to a tourist of a dive visit to Palau is the total utility or value enjoyed, minus the price paid (e.g., dive tour costs). Individual consumer surplus can be summed across all divers to obtain total consumer surplus. In the case of Palau's dive-tourism industry, the entirety of consumer surplus leaves Palau—it is the value that visitors take home. Like business profits, individual and total consumer surplus can be positive or negative. Unlike business profits, there are no explicit financial transactions that reveal an individual consumer's surplus, and it can only be estimated indirectly (and typically with relatively poor reliability). This paper focuses on estimates made of individual and total consumer surplus and how they may have been impacted by the coral bleaching event.

Consumer Surplus

In order to gauge the net value to visitors of their dive experience in Palau, the year 2000 survey respondents were asked how much more than their actual current costs they would be willing to pay to dive in Palau.

The question was expressed using a hypothetical permit that would allow them to dive in Palau for the duration of a single visit. How much a respondent would be willing to pay for such a permit was elicited by first asking whether he or she would be willing to pay US$100. The question was then repeated with the price raised or lowered, depending on the first response, until the highest willingness to pay (WTP) was revealed. The mean response was US$32, as shown in Table 1.

Although there was a difference of US$8 between the mean responses of scuba divers and snorkelers, the difference was not statistically significant (at a confidence level of 95 percent), due in part to a high degree of variation among the responses of the scuba divers. Other respondent attributes that were tested with

Table 1. Willingness to Pay for Permission to Dive in Palau *(US$/visit)*

	Scuba divers	Snorkelers	All divers
Mean	34	26	32
Median	20	30	20
Standard deviation	39	9	35
Minimum	0	10	0
Maximum	300	50	300

respect to being related to WTP included nationality, primary activity (scuba versus snorkel), previous diving experience (expressed as the number of other countries dived), number of previous visits to Palau, and age. Again, none of them were found to be significantly related to WTP. Personal income, which might be expected to be an important factor, was not elicited or tested with respect to WTP.

If it is assumed that the WTP statements did indeed reflect the net utility enjoyed by the respondents,[9] then the product of the mean response and the number of annual visiting divers is equal to total annual consumer surplus. With about 25,000 scuba divers and 25,000 snorkelers visiting each year (and assuming a different mean WTP for each of the two groups), the total consumer surplus would be US$850,000 for scuba divers and US$650,000 for snorkelers, for a total of US$1.5 million per year.[10]

The WTP responses can be used to construct demand schedules for diving in Palau. These schedules can be used to predict the impact of a given price, or permit fee, on visitation, on total fee revenues, on consumer surplus, and on producer surplus. Such analysis can help optimize the fee level in terms of a given tourism policy, such as Palau's policy to "attract high-return, low impact, quality travelers …" (PVA, 1999), while dampening the total visitation rate. These analyses are not presented here, but one important difference between the responses of snorkelers and those of scuba divers is noted. The demand curve for snorkelers was remarkably flat, indicating that small increases in the fee would result in large decreases in visitation (or, to the extent that other activities are available, a shift to non-marine-based activities). The curve for scuba divers was steeper, indicating that unlike the snorkeler population, at least a portion of the scuba diving population would be willing to pay quite high fees—among these respondents, as much as US$300 per visit.

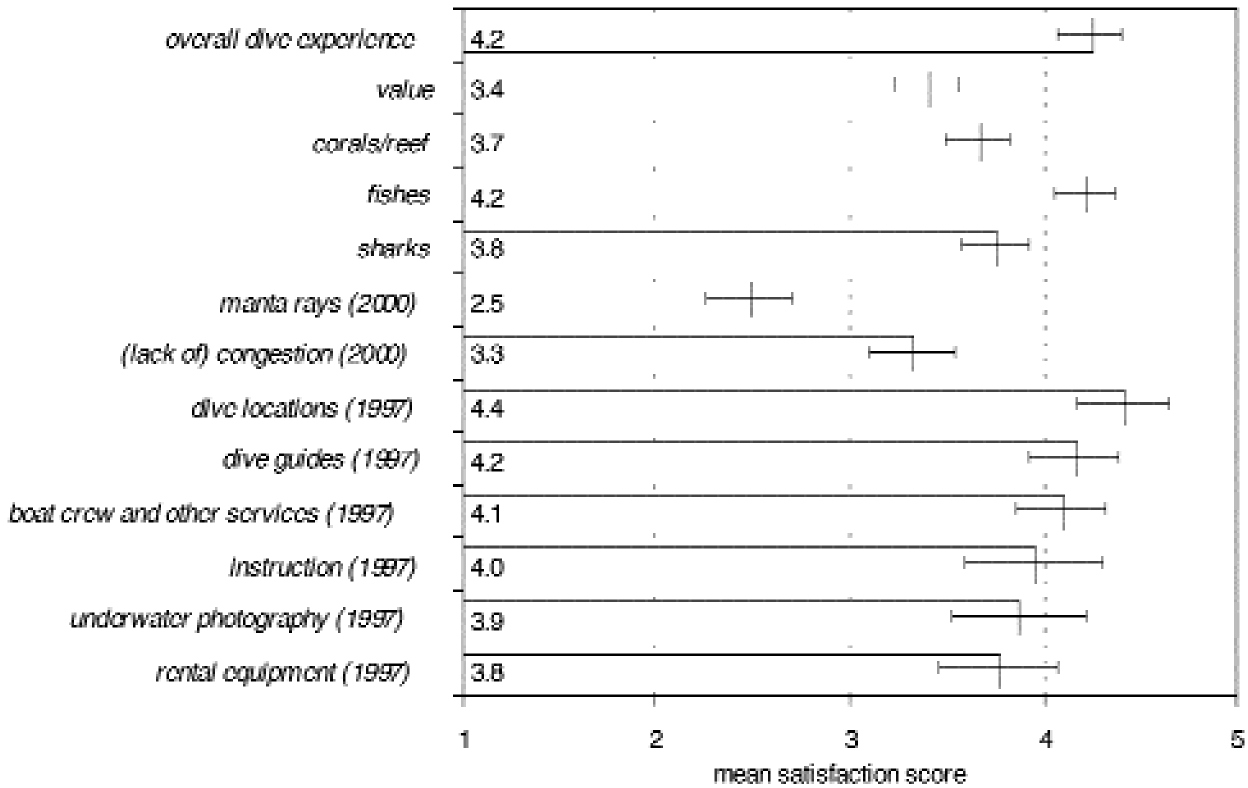
Diver Satisfaction

Two hundred visiting divers (100 in each of 1997 and 2000) were asked to rate on a five-point scale their

[9]In fact, this is a substantial leap, as there are undoubtedly some important biases in the approach; among them: 1) respondents may be reluctant to reveal their entire net value because of a risk of losing it (e.g., through permit fees), 2) the responses may reflect the respondents' opinions about permits and government intervention more than their net enjoyment, 3) the approach tends to preclude the possibility of respondents' expressing net values that are less than zero, and 4) it may be difficult for a respondent to separate the benefits and costs of the diving experience from those of the entire vacation trip to Palau.

[10]Although the permit was treated as a hypothetical device in the survey, the local government with jurisdiction over most of the Rock Islands/southern lagoon area, Koror State, has, in fact, been charging US$15 per visiting diver per month. With full compliance, the fee would result in the transfer of US$750,000 per year, or half of the otherwise available consumer surplus, to the people of Koror. Because the degree of compliance with the fee requirement is unknown and for the sake of simplicity and clarity in this paper, these fees will be ignored and the entirety of an individual's WTP, as measured here, will be treated as consumer surplus.

Figure 3. Mean Satisfaction Scores



- Satisfaction scores were rated as 1 = very poor, 2 = poor, 3 = moderate, 4 = good, and 5 = excellent.
- Error bars indicate 95% confidence intervals for the means, based on a pooled standard deviation.
- Attributes not suffixed with the year were rated in both years.
- The number of responses was 163-192 for categories rated in both years, and 37-100 for those rated in one year.

satisfaction with a variety of attributes associated with their diving experience in Palau. In Figure 3. is the mean score for each of 13 attributes.

There were numerous factors that may have influenced these satisfaction scores. Factors for which effects could be tested included year, primary activity, nationality, whether the diver was a first-time or return visitor, previous diving experience, the number of previous visits to Palau, and the age of the respondent. To test for these effects for each scored attribute, a general linear model was applied that incorporated these four factors and three variables. Table 2. summarizes the results, indicating for each attribute the factors and variables that were statistically significant, as well as the direction of the effect.

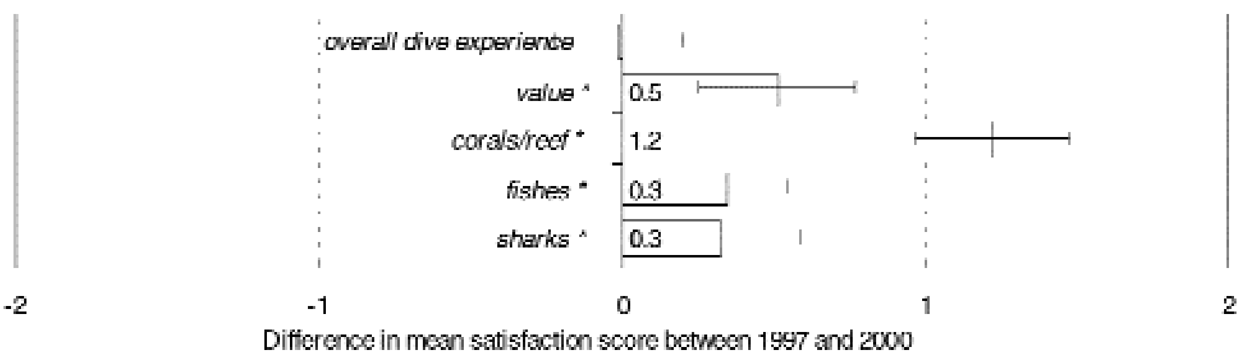
Of the 13 attributes, only five were scored in both 1997 and 2000. As shown in Figure 4., four of those attributes had means that were significantly different in the two years (after adjusting for the effects of the other factors and variables included in the models), and in all four cases, the mean scores were significantly lower in 2000 than in 1997. Interestingly, the one attribute with no difference was overall dive experience, an attribute intended to collectively describe all other attributes. It is not clear why the scores for overall dive experience did not parallel those of the other attributes. It suggests that those four attributes did not, in fact, collectively capture overall dive experience—that is, that they collectively made up only a relatively

Table 2. Summary of Satisfaction Score Effects

Satisfaction attribute	factors				quantitative variables		
	year (2000)	primary activity (snorkel)	nationality	return visitor? (yes)	previous diving experience	number of Palau visits	age
Overall dive experience			*		+		-
Value	-		*				
Corals/reef	-		*			-	
Fishes	-		*	-	+	-	
Sharks	-	-	*		+	-	
Manta rays (2000)	n/a	-	*				
Congestion (2000)	n/a		*				
Dive locations (1997)	n/a						
Dive guides (1997)	n/a						
Boat crew and services (1997)	n/a						
Instruction (1997)	n/a						
Underwater photography (1997)	n/a						
Rental equipment (1997)	n/a				+		-

- A blank cell indicates no significant effect. Any of the symbols , +, or * indicates a significant effect (at a 95% confidence level). Attributes not suffixed with the year were rated in both years, and the notation *n/a* in the year column indicates that the attribute was not rated in both years.
- For all factors and variables except nationality, the direction of the effect is indicated by - or +, and for the factors, the basis of the direction is given in parentheses in the column heading. For example, year and number of Palau visits had significant effects on *corals/reef*. Scores were lower in 2000 than in 1997 and scores decreased with increasing number of Palau visits.
- The number of cases was about 200 for attributes rated in both years and about 100 for those rated in one year.
- Note that none of these factors or variables was significantly related to WTP (which was measured in 2000 only).

Figure 4. Differences in Satisfaction Between 1997 and 2000



- These differences have been adjusted for the effects of nationality, primary activity, first-time versus return visitor, diving experience, number of previous visits to Palau, and age, as summarized in Table 2.
- Error bars indicate 95% confidence intervals for the differences in means between 1997 and 2000; those significantly different from zero are indicated with an asterisk.

minor portion of the overall dive experience. Alternatively, it is possible that the respondents misinterpreted the intended meaning of overall dive experience. For example, they may have instead tended to score their overall vacation experience. Despite the lack of a difference in overall dive experience between 1997 and 2000, there were large differences in mean scores between the two years for the other four attributes, particularly corals/reef, which had a difference of 1.2 points on a five-point scale. The likelihood of this difference being related to the coral bleaching event will be addressed in the following sections.

Relationship Between Satisfaction and Value

The relationships between WTP and the satisfaction scores for various attributes of the diving experience, as summarized in the preceding sections, were examined. Remarkably, none of the rated attributes, including overall dive experience, congestion, corals/reef, fishes, sharks, manta rays, or even value had a significant relationship with WTP. The lack of any relationships—especially with overall dive experience and value—suggests that WTP, as measured here, may not have been a very accurate or useful measure of diver satisfaction or value.

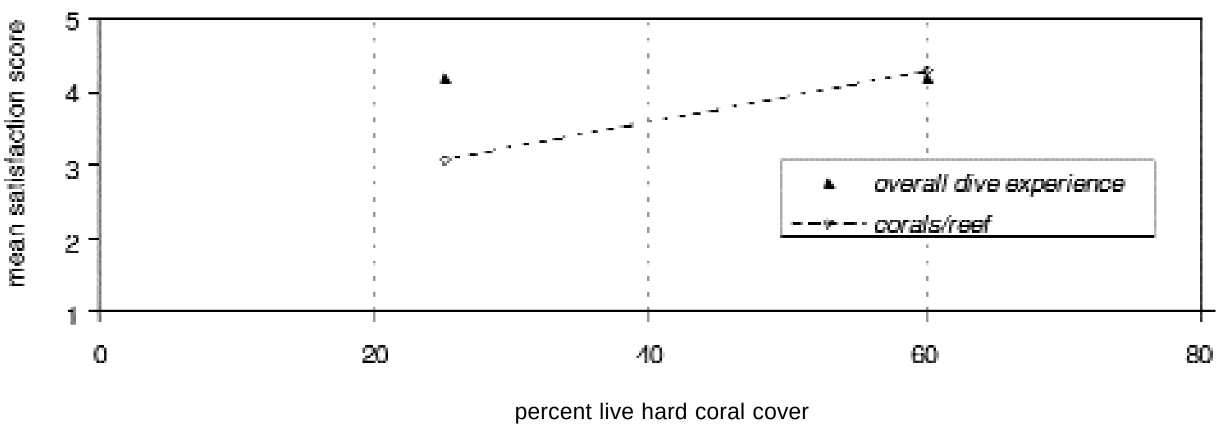
Visiting divers in the year 2000 were also asked if and how their willingness to pay to dive would change under various hypothetical conditions of the attributes they had already rated. For each of the attributes, two yes/no questions were asked. For the attribute corals/reef, for example, they were asked, first, whether or not they would be willing to pay more than previously stated, if the condition of the corals/reef were better, and second, whether they would not be willing to pay as much as previously stated, if the condition of the corals/reef were worse. In general, the number of no/no responses (meaning that WTP was not at all responsive to changes in the condition of the attribute) was remarkably high, being consistently around 50 percent for all attributes except overall dive experience. And even in the case of overall dive experience, 32 percent of respondents indicated that their WTP would not change with either increases or decreases in the quality of their overall dive experience (no/no responses). Only 10 percent of respondents said that their WTP would change under both increases and decreases in the quality of their overall dive experience (yes/yes responses).

Another set of questions was used to quantify the responsiveness of the divers' WTP under each of various hypothetical scenarios (for each attribute, the respondents were asked to state their hypothetical WTP under each of the five points on the five-point scale, which corresponded to conditions ranging from very poor to excellent). Only a few respondents were able to provide thorough quantitative responses. There was also a high degree of variation among respondents. It was therefore not possible to reach any definitive conclusions about the average relationship between WTP and the condition of any of the attributes. However, after applying a number of simplifying assumptions, including one that the relationship between WTP and the quality of each attribute (treating the five-point scale as integral data) was linear, some relationships were revealed that are useful, at least for illustrative purposes. First, there were no apparent differences among the six attributes in the slopes of WTP on attribute or condition. Second, the average slopes appeared to be roughly US$3 per point, meaning that the average WTP would increase US$3 for every increase of one point in attribute quality, or US$12 across the entire five-point scale. If this relationship were applied to the difference between 1997 and 2000 of 1.2 points in the attribute corals/reef, it would imply a difference of almost US$4 in individual consumer surplus, or a loss of about 10 percent. It should be emphasized, however, that there was no difference between 1997 and 2000 in the mean satisfaction score for overall dive experience, which is somewhat at odds with this (somewhat speculative) relationship between WTP and the quality of corals/reef. In summary, it is likely, but not entirely clear, that average WTP in 1997 (which was not directly measured) was less than in 2000.

Relationship Between Value and Condition of the Reef

If we consider Ngerumekaol, as described in the first section, to be a typical dive site,[11] then the relationship between percent live hard coral cover and satisfaction with corals/reef, as rated by visiting divers for Palau as a whole, can be illustrated as in Figure 5. The slope of corals/reef on live coral cover was about 0.03 points per percent, meaning that for every decrease of 10 percent in live coral cover, there was a 0.3-point drop in satisfaction with corals/reef. Applying the (somewhat speculative) relationship between WTP and corals/reef of US$3 per point, then the slope of WTP on live coral cover was about US$0.10/percent, indicating a drop in individual WTP of US$1 for every 10 percent decrease in live coral cover. This relationship is, of course, relevant not just to the impacts of coral bleaching, but to reef degradation from any cause, including diving itself. It should be emphasized that these data were purely observational and that no cause-and-effect relationships can be directly deduced from them; further, that the assumptions used in these last

Figure 5. Relationship Between Satisfaction and Live Coral Cover



couple of steps were so simplistic that the results are somewhat speculative. Further, as shown in Figure 5., there was the somewhat contrary finding that mean satisfaction with overall dive experience did not change between 1997 and 2000 and so the slope of overall dive experience on live coral cover was zero.

Impacts of the Bleaching Event on Diver Satisfaction

The dramatic biophysical impacts of the coral bleaching event are obvious candidates for the cause of the difference in satisfaction scores between 1997 and 2000 for the attribute corals/reef (and perhaps for fish, sharks, and value, as well). To provide more direct evidence of any cause-and-effect relationship between those impacts and diver satisfaction, the year 2000 respondents were asked a series of questions about their

[11] The impacts of the bleaching event varied widely by area, habitat, and taxa, but Ngerumekaol is a useful example because the impacts there were moderate and because it is used by both scuba divers and snorkelers.

Table 3. Knowledge and Notice of Coral Bleaching

	Know corals are living?	Familiar with the effect of corals being bleached and killed?	Know that much of Palau's corals recently killed by bleaching event?	Notice any effects of that bleaching and killing event?
Yes (%)	95	81	59	53
Unsure (%)	4	3	6	9
No (%)	1	16	35	38
No. of respondents	98	99	99	99

knowledge and notice of the coral bleaching event. The surveyors made no mention of the bleaching event until all the previously discussed questions were answered. The results are shown in Table 3.

Ninety-five percent of respondents claimed to know that corals are living organisms and 81 percent said they were familiar with the effect of corals being bleached and sometimes subsequently dying. Fifty-nine percent knew about the bleaching event in Palau and virtually all of those noticed the effects. There were a few factors that had significant effects on the responses for some of these questions, including nationality, primary activity, and whether or not the respondent was a first-time visitor to Palau. For example, significantly greater proportions of both scuba divers and return visitors were familiar with the effect of coral bleaching and knew about the recent bleaching event in Palau. However, there were no significant differences between these groups regarding the last question—whether or not the effects of the bleaching event were noticed.

Table 4. Impact of the Bleaching Event on Overall Dive Experience

Degree of impact	**Among only those with knowledge or notice (%) (n=59)**	**Including those with no knowledge or notice (%) (n=99)**
Improved it	2	1
No impact	27	57
Slightly negative	42	25
Very negative	29	17
Ruined it	0	0

- Only the 59 respondents that had no knowledge of, and did not notice the effects of, the bleaching event were asked this question; the right-hand column includes the other 40 respondents under the *no impact* category

The 59 respondents who knew about or noticed the bleaching event were asked how such knowledge or notice affected their diving experience. The results are shown in Table 4.
Seventy-one percent of the 59 respondents described the impact as either slightly or very negative. Only 29 percent cited either no impact or an improvement, but that proportion increases to 57 percent when the entire original sample is accounted for—that is, if the 40 respondents that did not know about or notice the effects of the bleaching event are included under the no impact category. There were significant differences in these responses according to various attributes of the divers, including primary activity (snorkelers rated the impact more negatively than did scuba divers), previous diving experience (more experienced divers rated the impact more negatively), and whether the respondent was a first-time visitor to Palau (return visitors rated the impact more negatively).

CONCLUSIONS

The responses of visiting divers regarding their knowledge and notice of the impacts of coral bleaching, along with the differences in satisfaction scores between 1997 and 2000, show that visiting divers clearly discerned differences in the condition of the reef, and further, that those differences were reflected in expressions of their satisfaction. However, there was somewhat inconsistent evidence regarding the degree to which satisfaction with the condition of the reef was related to overall satisfaction and value. Diver responses to direct questioning on the effects coral bleaching had on their diving experience, shown in Table 4., suggest that there was a moderately strong link between the condition of the reef and overall satisfaction. The diving attribute satisfaction scores, however, show that scores for the attribute corals/reef did not correspond with any difference in scores for overall dive experience. The responsiveness of WTP to changes in corals/reef indicated a lukewarm relationship, with about one half of respondents stating that their WTP was at least partially dependent on the condition of the reef.

The 1998 coral bleaching event resulted in detectable but not dramatic impacts on the net value of dive-tourism in Palau. The number of tourists visiting in 1999 was probably as much as 5 percent, and possibly as much as 10 percent, less than it would have been without the bleaching event, with proportional impacts on both consumer surplus and producer surplus. Average individual consumer surplus appears also to have been impacted, but probably by no more than 10 percent. The two effects together, therefore, may have caused negative impacts to total producer surplus of as much as 10 percent and to total consumer surplus of as much as 20 percent (i.e. roughly US$350,000/year) in the two years following the bleaching event.

This study examined impacts only one year after the bleaching event. No predictions or analyses were made of possible future impacts. Processes that will be important in the next decade include the gradual breakdown of the physical structure of the reef, as dead corals erode and collapse, and the recovery of coral communities through growth, fragmentation, and recruitment of new coral colonies. Even more important will be the frequency and intensity with which coral bleaching events occur in the future. Two other factors that will influence future economic impacts in Palau are the degree to which Palau's tourism industry remains dependent on reef-based activities and, given the competition among dive destinations worldwide, how the condition of the reefs in other countries changes relative to those in Palau.

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MANAGEMENT OF BLEACHED AND SEVERELY DAMAGED CORAL REEFS

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ABSTRACT

The 1997-98 coral bleaching event caused extensive reef damage in many regions of the world. Countries in severely impacted regions such as the Indian Ocean (where coral mortality reached over 90 percent in some areas) are now at serious risk of losing this valuable ecosystem and associated economic benefits from fisheries and tourism. If average baseline temperatures continue to increase due to global climate change, then corals will be subjected to more frequent and extreme bleaching events in the future. Thus, crucial management questions must be addressed, and potential tools for mitigating bleaching must be analyzed. While more scientific information is needed for precise recommendations, there is also an immediate need to adapt current knowledge into general management guidelines for use as a rapid response measure. Drawing on data from the Coral Reef Degradation in the Indian Ocean (CORDIO) program and from other studies, we have developed a management handbook that:

1. Summarizes current scientific opinions on the causes and consequences of bleaching
2. Discusses precautionary and response measures to be taken in light of the bleaching threat
3. Suggests some positive actions that might aid reef recovery.

The analysis is based on specific case studies, but the recommendations are of global applicability.

INTRODUCTION

Until recently, stresses caused by human activities—such as land-based sources of pollution and destructive fishing practices—were considered to be the primary dangers to coral reefs. While these problems persist, the last two decades have seen the emergence of yet another, potentially much greater threat: climate change and associated coral bleaching. Coral bleaching (loss of symbiotic algae that provide corals with nutrients as well as color) is associated with a variety of stresses, but especially increased sea water temperatures. There is significant evidence that climate change is a primary cause of recent large-scale bleaching events.

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Severe and prolonged bleaching can lead to widespread coral mortality. The 1997-98 coral bleaching event caused extensive reef damage in many regions of the world (Wilkinson, 2000). The event was especially severe in the Indian Ocean, where coral mortality reached over 90 percent in some areas.

Even in regions where reefs escaped major damage from the 1997-98 event, there is grave cause for concern. If climate change trends continue as predicted, coral reefs will probably be subjected to more frequent and severe bleaching events in the future. As average baseline temperatures increase due to global climate change, there will be an ever-increasing probability that fluctuations in sea surface temperature will exceed the temperature tolerance of corals more often, and with greater severity. Furthermore, there is little indication that individual corals can acclimate or that coral species can adapt fast enough to keep pace with global climate change; thus, local and even global species extinctions could result.

Increased sea water temperatures are not the only threat associated with global climate change. Global emissions of greenhouse gases are raising concentrations of carbon dioxide in the atmosphere (and oceans) to a level that may gradually reduce the ability of corals to grow their calcium carbonate skeletons. High levels of carbon dioxide increase the acidity of the water, which in turn inhibits calcification. It is predicted that calcification rates may be reduced by as much as 14-30 percent by the year 2050 (Hoegh-Guldberg, 1999). This will reduce the capacity of reefs to recover from events such as coral bleaching. Hence, global climate change represents a dual threat to coral reefs, not only through direct mortality (from bleaching), but also through inhibition of reef recovery (calcification).

Consequently, countries in many regions are now at serious risk of losing part or all of their valuable reef ecosystems, with potentially serious socioeconomic consequences. In countries such as the Maldives, for example, the economy has traditionally been based on fisheries and tourism. Both of these activities can be linked directly to the reefs, which have been severely affected by bleaching. This bleaching, combined with ongoing direct human impacts of over-fishing, pollution and coastal development, will have potentially major economic, as well as ecological impacts. For human populations dependent on reefs, future livelihoods will depend on reef recovery (regrowth). Crucial management questions must therefore be addressed as soon as possible. Managers and stakeholders are already raising the following issues:

- At what rate can reefs be expected to recover and what actions should managers take to aid and accelerate regeneration?
- How can managers convince policymakers and government agencies of the value of maintaining marine parks and conservation efforts, in the face of severely damaged reefs?
- What economic impact will bleaching have, particularly on human livelihoods, and how can such impacts be mitigated?
- In particular, how will tourists react to bleached reefs? What action should the tourism industry take?
- Will bleaching affect reef fisheries, and if so, how?
- When should active reef rehabilitation methods be used? Which methods are successful and economically viable? In which situations?

- Can we prepare for bleaching events in the future?

Scientific information, particularly on coral recovery and resilience, is not yet adequate for precise recommendations to be made, but new information is constantly being generated. Meanwhile, it is clear that the knowledge that is currently available must be transferred to those in a position to protect the remaining resources and stimulate recovery. The Secretariat of the Convention on Biological Diversity, the World Conservation Union (IUCN), the World Wildlife Fund (WWF), and the US Agency for International Development (USAID), in association with the International Coral Reef Initiative, have therefore produced guidelines on Management of Bleached and Severely Damaged Coral Reefs (Westmacott et al. 2000a). The goal of these guidelines is to provide information and recommendations to local managers, policymakers, and stakeholders on appropriate management strategies for coral reefs that have been severely degraded through bleaching or other causes.

The CORDIO program in the Western Indian Ocean is one example of efforts to gather information on the biological and socioeconomic implications of severe bleaching events. Drawing on data from CORDIO and from other studies, Westmacott et al. (2000a) review current scientific opinions on the causes and potential consequences of coral bleaching (within the context of other causes of reef degradation), provide suggestions for positive actions that might aid reef recovery, and propose precautionary measures to be taken in preparation for future bleaching episodes. The analysis is based on specific case studies, but the recommendations are of global applicability for managers, policymakers, and the international community. These recommendations are reviewed below.

Management Actions

The basic assumption behind the guidelines is that, given the right environmental conditions and a sufficient period of time, reefs will regenerate. There is encouraging evidence from long-term studies that coral reefs can recover from major events such as hurricanes, provided that other negative impacts are minimized. Indeed, increasing numbers of studies are showing that during bleaching events, some corals or patches of reef remain unaffected and thus provide a basis for asexual, as well as sexual, reef regeneration. In some cases, reefs may evolve into communities that are substantially different from those existing prior to the bleaching event, yet they may still be diverse and thriving ecosystems. Many of the optimal conditions for reef regeneration are now understood and include:

- A solid submerged surface, free from algae, on which coral larvae can settle
- Sexually mature corals, either close by or upstream, to provide larvae
- Suitable prevailing winds, currents and upwellings to bring larvae and cool waters to the area
- High coral diversity
- Healthy fish populations
- Minimal human impact

A management strategy to deal with bleached coral reefs will therefore need to consider the following aspects:

1. Rapid Response Actions

- Survey the area to identify those areas with the least damage and greatest chance of recovery. This assessment may be difficult in developing countries that lack the capacity or resources for such rapid response measures. An international fund for such activities is needed.
- Ensure that remaining live corals and reef areas are protected; this may require reviewing and revising zoning schemes and boundaries of marine protected areas (MPAs).
- Halt (or impose a moratorium on) activities that may damage remaining live corals, such as diving, anchoring, coral collection.
- Assess the impact of bleaching on fisheries, tourism and local communities.
- Set up a monitoring program to track recovery. Monitoring will enable managers and policymakers to track changes on the reef and assess the success of management programs. Care must be taken to design programs that fit within the personnel and financial capacities available in each case. In many cases, there are existing programs that can be adapted.

2. Tourism

Bleaching is of major concern in relation to the tourism industry, since in many areas this industry is dependent on healthy reefs. Considerable socioeconomic research has been undertaken to assess and predict the potential impact of bleaching on the industry (e.g., Westmacott et al. 2000b). The resulting data indicate some of the issues that should be taken into consideration in management:

- Maintaining healthy fish populations for the enjoyment of divers and snorkelers through creative use of zoning to reduce pressure from overfishing and frequent tourist visitation
- Involving tourists in the bleaching issue by offering opportunities for participation in monitoring and assessment programs
- Emphasizing other attractions for tourists besides coral reefs, both on land and in the water, while corals recover
- Reducing the impacts from tourism operations in general, such as direct damage to corals from divers and snorkelers or from boat anchors, and indirect damage from coastal activities that support the tourist industry (i.e., by enforcing regulations)
- Encouraging tourists to contribute financially to recovery and management efforts

3. Fisheries

The potential impact of bleaching on fisheries is still unclear, and it appears that the full effect may only be felt on a longer time-scale than has been measured so far. Negative impacts may not be felt until reefs that have suffered major mortality start losing their physical structure (thereby becoming unable to support a diverse and abundant fish community). Potential changes in a reef fishery due to bleaching include:

- Decreased yields of both reef fish and pelagic species that prey on reef fish
- Shifts in catch composition (e.g., towards lower-value herbivorous species)
- Reduction in income for fishing communities
- Increased use of damaging fishing methods as stocks shrink and fishing pressure intensifies
- Changes in fishing areas for certain target species

A precautionary approach can be taken by giving specific attention to the following:

- Establishing no-fishing zones and limitations on fishing gear to protect breeding grounds and provide fish with a refuge
- Considering specific protection measures for species that can contribute to reef regeneration, such as algal grazers, or that might be affected by coral bleaching, such as coral-eating fishes
- Enforcing legislation that prohibits destructive fishing practices
- Monitoring catch composition and size to evaluate the success of management strategies, and implementing new strategies, if necessary
- Developing alternative livelihoods for fishing communities, as needed
- Limiting entry of new fishermen to a fishery through licensing schemes
- Involving local fishing communities in assessment and monitoring

4. Reef Rehabilitation and Restoration

The question will inevitably arise as to how much active intervention should be encouraged. The most cost-effective and sustainable approach is to allow natural regeneration. Costly rehabilitation programs may be a risk rather than a cure, and artificial rehabilitation should not be considered unless efforts are also made to halt human-induced stresses in the area. When considering restoration options, managers should assess methods, costs and feasibility and ask the following questions:

- What are the objectives of the restoration project?
- What is the scale of the restoration project?
- What will be the cost of the project, and is it affordable?
- What is the success rate of the method being proposed, and which method will be most cost-effective at the site?
- What will be the long-term viability of the program?
- Is there scope for the local community and reef users to become involved?

There may be certain situations in which some form of active intervention is beneficial, and there is clearly a need for further research on this topic. Restoration methods include:

- Allowing natural recovery by removing stresses
- Increasing substrate for larval settlement (e.g., providing artificial substrates)
- Transplanting corals from other areas
- Farming corals for later transplantation

5. Marine Protected Areas (MPAs)

MPAs already play an important role in protecting healthy reefs by maintaining areas with minimum negative human impact that will help reef regeneration by providing sources of coral larvae. However, a more strategic approach to MPA design and planning is needed, with greater attention to designing systems of MPAs that take into account concepts of connectedness, resilience, refugia and the potential for recovery of different coral communities and species. In particular, attention should be paid to:

- Areas that have a lower vulnerability to bleaching (e.g., due to cold water upwelling, shading, or presence of turbid water) Evidence from several locations suggests that reefs in such locations have a greater resilience (see Salm et al. in this volume).
- Sources and sinks of coral larvae
- A wide geographic and ecological spread of MPA types, covering all types of reefs and associated habitats throughout each region
- Ensuring that existing MPAs are effectively managed

Integrated Coastal Management (ICM)

Integrated coastal management (ICM) considers the coastal zone and its associated watershed as a single unit and attempts to integrate the management of all relevant sectors. It is an essential tool in the maintenance of a healthy coastal zone, which will, in turn, contribute to reef regeneration and may enhance reef resiliency. From the perspective of coral bleaching, particular aspects of ICM that need emphasizing include:

- Establishing MPA systems within an ICM framework
- Implementing measures to promote sustainable fisheries
- Implementing mechanisms to promote environmentally sound construction and other forms of land-use and coastal development
- Regulating land-based sources of pollution
- Managing shipping and other vessels to reduce damage to reefs from physical impacts or spills
- Protecting the coastline from erosion and ensuring that ICM strategies and plans take into account the future scenario of increased impacts from global climate change, including coral bleaching and sea level rise

Public Education and Outreach

Education and outreach will be essential for establishing and maintaining public support for coral reef conservation, in the face of climate change. Given the global nature of the problem, sustained coordinated management efforts are needed at local, national and international levels—and none of these efforts will succeed in the long term without public understanding, involvement and financial investment.

At the local level, important public education and outreach activities could include:

- Developing fact sheets on the dos and don’ts of enjoying coral reefs and on the relationship between climate change and coral bleaching. These could be distributed through local hotels, dive shops, etc.
- Creating colorful and informative posters that can be sold in local tourist shops or park offices
- Offering training courses for tourist and park operators on how to educate the local community, as well as visitors, about reef biology, the socioeconomic value of reef “services,” and the threats to reefs
- Providing free boat tours of MPAs and slide show lectures for members of the community, especially those who interact with visiting tourists, so that they will feel a sense of stewardship toward their reefs and will help to educate the tourists that they meet

At the same time, coral reef managers and policymakers must act now to tackle issues of global climate change through outreach with the wider global community. At national and international levels, this would involve:

- Submitting reports on coral bleaching and reef degradation to national, as well as local, policymakers. and to delegates of international treaty conventions, expressing ongoing concern for the effects of climate change on coral reefs and other ecosystems, and calling for continued attention to the problem in international forums
- Calling on international bodies to make financial commitments toward capacity building, rapid response, and management implementation
- Speaking out in support of international efforts to reduce harmful emissions of greenhouse gases
- Encouraging national and individual commitments to altering current lifestyles that have led to these worldwide changes

Conclusion

Action at all levels—from local communities and stakeholders to national governments and decisionmakers—is required immediately to address not only issues related to coral bleaching, but also the general state and plight of coral reefs everywhere. The Conference of the Parties to the Convention on Biological Diversity is currently integrating coral reef ecosystems into its program of work on marine and coastal biological diversity. It has also urged Parties, other Governments and relevant bodies to implement a range of response measures to the phenomenon of coral bleaching and the physical degradation and destruction of coral reefs, including research, capacity building, community participation and education. Reef managers, in particular, can play a major role in preparing for bleaching events and aiding reef recovery. The guidelines provided in Westmacott et al. (2000a) should assist in identifying priority actions in particular situations, and can be used as a baseline for more strategic, planned responses to the coral reef crisis.

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MITIGATING THE IMPACT OF CORAL BLEACHING THROUGH MARINE PROTECTED AREA DESIGN

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ABSTRACT

The 1997-1998 El Niño event caused mass coral bleaching of unprecedented proportions. Events of this nature are expected to occur with greater frequency and intensity over the coming decades, which calls for urgent and effective measures to mitigate their impact on coral communities at scales that are significant. Patterns of bleaching and subsequent mortality induced by elevated seawater temperature provide insights into factors influencing the differential susceptibility of coral assemblages.

This paper presents some preliminary ideas on how these patterns might be used to develop selection and design principles for marine protected areas (MPAs) that enhance survival and recovery prospects for coral communities affected by El Niño Southern Oscillation (ENSO)-related bleaching.   If these principles prove effective, a global review of all coral reef MPAs may be required.

BACKGROUND

Climate change is likely to have significant impacts on marine biodiversity (Buddemeier, 1993; Hoegh-Guldberg, 1999; Wilkinson, 1996, 1999). Sea level rise will affect turtle-nesting beaches, low-lying seabird colonies, and mangroves, to name some of the more obvious probable casualties. Elevated sea surface temperatures (SSTs), whether or not linked directly to climate change, can cause corals to bleach (Glynn, 1996; Brown, 1997; Hoegh-Guldberg and Jones, 1999) and die, and have far reaching impacts on the diversity of dependent organisms.

Large-scale bleaching events have increased in intensity, frequency, and local and geographic distribution in the last two decades (Wilkinson, 1998, 2000). In 1998, the worst year on record, complete loss of live coral in some parts of the world occurred (Goreau et al., 2000). Bleaching spanned the tropics and over 50 countries, proving the global nature of the event (Wilkinson, 2000). Such large-scale bleaching is attributed to thermal stress, in particular to hotspots[4] (Hoegh-Guldberg, 1999), linked to perturbations in normal oceanic or atmospheric circulation patterns. In 1998 the distribution of hotspots and subsequent bleaching coincided with the largest El Niño Southern Oscillation (ENSO) on record. The massive scale of the 1998 El Niño- and 1999 La Niña-related coral bleaching, and subsequent mortality, point to an urgent need for rapid action to mitigate the impact of temperature-induced coral mortality and to enhance the prospects for coral recovery (Westmacott et al., 2000).

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[4]A hotspot is an area where sea surface temperatures (SSTs) have exceeded the expected yearly maximum (the highest temperature per year, averaged for a 10 year period) for that location (Goreau and Hayes, 1994).

We now realize that bleaching events and phenomena related to climate change pose a serious global threat to coral reefs and need to be incorporated into practical management and planning guidelines (Goreau et al., 2000; Westmacott et al., 2000). Our specific interest is how we can help preserve biodiversity in the seas by mitigating the impact of coral bleaching, and its related mortality, through design of marine protected areas (MPAs) (Salm et al., 2000). Although we recognize that active intervention through direct restoration of damaged reef sites is possible and useful in certain circumstances, it is expensive, labor intensive, and limited in scope. We believe that enhancing the prospects for natural recuperation and replenishment through a more passive approach merits serious consideration. Given the widespread mortality linked to the 1997-1998 El Niño event, it could also help to achieve recovery of reefs at both sites and scales that are significant.

This paper presents the concept for a strategy to develop principles that would guide MPA design to enhance survival and natural recovery of coral communities. Its particular goal is to solicit feedback on the premise and design of the project, the merits of these ideas, personal observations on patterns of bleaching-induced coral mortality, and guidance on how to improve upon this initial proposal.

CONTEXT

In addition to temperature stress, other potential causative agents of coral bleaching include freshwater flooding, hyper-salinity, sedimentation, pollution, oxygen depletion and other physical and chemical stresses (Westmacott, et al., 2000). Where bleaching is locally restricted, the source of the stress is commonly related to poor management practices in adjacent riparian zones. In such cases, we can intervene directly at the source of the stress (e.g., reforestation and other erosion control measures) to abate the threat. Such interventions should form part of the reef management practices at any protected area site, and are, indeed, addressed in many integrated coastal management and MPA management programs (Salm et al., 2000).

With large-scale regional or global bleaching events, thermal stress is linked to perturbations in normal oceanic or atmospheric circulation patterns, such as ENSO, coupled with rising sea surface temperatures in the tropics (Watson et al., 1996). Where the cause lies with factors that are driving global climate change and global warming, we are powerless to intervene at the source to control the stress, at least in meaningful time frames, given the increasing frequency and intensity of these events over the past two decades. The best we can do is to try to mitigate the impact of bleaching-induced mortality in two broad ways:

- Recognize and protect specific patches of reef where conditions are more likely to ensure low or negligible ENSO-related coral bleaching and mortality.
- Enhance coral recovery by ensuring optimal conditions for larval dispersal and recruitment to damaged sites. This will require understanding larval dispersal, as well as managing other stresses at these sites (including causes of bleaching mentioned above, fishing, anchor and diver damage, and waste disposal, among others).

The challenge is how to achieve this goal. The patterns in coral bleaching and related mortality, evident since the 1997-1998 El Niño, provide some insights.

Susceptibility and Resilience to Bleaching

Despite the widespread mortality that has followed many bleaching events, particularly that of 1998, it is rare for total elimination of living corals to occur. Even in the most severe cases, small patches of reef or individual colonies appear to be more resilient, and to survive. In most cases, new coral recruits and recolonization of dead skeletons can be observed within a year of the event, providing the starting point for reef regeneration. A recent analysis of bleaching reports (Wilkinson, 2000) indicates that there is a wide variability in intensity, species affected, depth, geographic distribution, and how much mortality a bleaching event causes.

We have observed that individual coral colonies are not equally affected by bleaching, and that colony recovery can be greatly enhanced by the survival of coral tissue in parts of the colony that are more shaded, or where particular determinants of what have been called microclimates favor survival. We have observed, too, that some coral colonies show greater resistance to bleaching, and subsequent mortality, than others of the same coral species on the same patch of reef.

We also have observed that patches of corals in different parts of the same reef may show greater or lesser susceptibility to ENSO-related bleaching and subsequent mortality. This differential response to temperature stress by diverse members of the same coral community provides us with a great opportunity to manage reefs around these pockets of resilience (or lower susceptibility) to enhance the survival and recovery of coral communities and to preserve their biodiversity.

In summary, there appear to be both intrinsic physiological factors and extrinsic situational factors that determine a coral's resilience to bleaching. Intrinsic physiological factors (Rowan et al., 1997) are difficult to control from a spatial management perspective; however, differences in bleaching susceptibility due to external environmental factors can be studied and incorporated into management planning. Based on our own observations, and conforming with those discussed on the Coral List (NOAA, 2000), environmental factors that reduce or prevent coral bleaching and related mortality include the following situations:

- Areas of upwelling (e.g., corals bleached immediately and comprehensively at one site in the Sultanate of Oman where SSTs reached 39 degrees Celsius in an area of local upwelling and good mixing. Within days the temperature had fallen to back down to 29 degrees Celsius and the corals recovered completely over time [Salm, 1993; Salm et al., 1993]).
- Areas with strong currents (e.g., corals in the southern communities where currents are strong in Komodo National Park in Indonesia did not bleach, while those in the sheltered northern reefs exhibited some bleaching [Pet, 1999, pers. com.]).
- Reefs with emergent corals, which already tend to be stress tolerant (e.g., corals on reef flats in the Rock Islands of Palau [pers. obs.] and Chumbe Island in Tanzania [Riedmiller, 1999, pers. com.] suffered significantly less bleaching than corals down the reef slopes).
- Corals which are strongly shaded and protected from prolonged exposure to direct sunlight and UV radiation (e.g., the same species of tabular Acropora and Porites that were severely bleached, and evidently dead or dying, in the Rock Islands in Palau, were alive and healthy in appearance in deeply shaded parts of the same reef [pers. obs.]).

- Corals from turbid areas survive better than those in clearer adjacent waters. Presumably, this is because they are better able to cope with salinity, temperature, and turbidity changes, and may be screened from damaging sunburn by refraction and absorption of UV radiation (e.g., Ngeremeduu Bay in Palau, where corals were little affected compared to the barrier reef off the bay, where coral bleaching and mortality was extensive [pers. obs.]).

Good water mixing and, in certain cases, tolerance of high stress levels seem important in fostering resilience to bleaching and consequent mortality. The impact of elevated SSTs on coral bleaching can be mitigated, and recovery enhanced, by combinations of the above conditions. For example, reefs around Bali Island showed differences in the onset of bleaching and the rate of recovery that appear linked to currents and upwelling. The colder waters around Nusa Penida appeared to moderate the impact of bleaching and enhance recovery (Sarjena Putra, 2000, pers. com.).

While this is not always the rule, corals in protected areas may fare better than those in unprotected sites. For example, in the 24 months following the 1998 bleaching event along the northern Tanzania coast, corals in reefs closed to fishing by local villagers had almost three times the density of coral recruits compared to open reefs. The reason for this may be that protected areas offer a better supply of larvae for replenishment, and that protected areas relieve anthropogenic pressures on the reef, which might otherwise compound the effect of elevated water temperatures.

There is no immediate cure for coral bleaching. However, these observations indicate that susceptibility to bleaching-induced coral mortality, and subsequent recovery, differs among similar coral assemblages on the same reef and within the same reef complex. We propose that understanding these patterns of bleaching will provide insights into the environmental determinants of greater or lesser susceptibility to bleaching and will yield some valuable principles for coral reef biodiversity conservation.

Of particular interest to us is how this understanding can yield criteria for reef site selection and guidelines for MPA design that will help to protect resilient coral patches covering the range of reef diversity so that they are able to replenish damaged areas through larval dispersal and recruitment.

Marine Protected Area Selection and Design—A Way Forward?

Field observations support the potential for MPAs to play an increasingly important role in sheltering biodiversity in coral reef ecosystems from climate-related impacts and in the recovery of corals from massive bleaching events. MPAs contribute to reef conservation and management by protecting resilience, areas of undamaged reef and sources of larvae, and by providing areas free of anthropogenic impact with suitable substrate for coral settlement and growth (Salm et al., 2000). However, most current MPAs were not selected or designed with this in mind, nor are they managed specifically for this purpose.

New science-based principles are needed to guide the design and management of MPAs to enable them to maximize coral survival and recovery from bleaching, and to mitigate the adverse impacts of climate-related threats to biodiversity in coral reef ecosystems. For example, zoning schemes or MPA boundaries may need to be revised in order to assure protection for corals more resistant to bleaching, sources for coral recruitment, or areas suitable for coral settlement and growth.

Several efforts to mitigate bleaching-related coral mortality are either under consideration or being carried out. In most cases, when specific mitigation measures are proposed, they include a collage of measures that apply broadly to restoration of reef damage caused by boat anchors, destructive fishing practices, and similar activities, as well as by storm damage (Westmacott et al., 2000; Wells et al., this volume). There is nothing proposed that is specific to coral bleaching or that links the patterns of resilience and susceptibility of corals to bleaching induced by SST change with mitigation measures at scales large enough to matter in the face of the challenge.

To address this need, the Asia Pacific Program of The Nature Conservancy (TNC) and the World Wildlife Fund (WWF) are planning to jointly develop sound, science-based, empirically-tested principles to guide the selection, design, and management of MPAs to enable them to maximize coral survival and recovery from ENSO-related bleaching events. Implementation of these principles represent one, as yet unexplored, means to mitigate the impact of coral bleaching and related mortality, and would be expected to increase the prospects for reef survival and recovery. Principles will be developed through the identification of patterns of variation in coral bleaching, resilience, and recovery with respect to external environmental factors. These results will be validated and promulgated as principles for design of MPAs that build on resilience and larval dispersal patterns. This endeavor would include five principal activities:

1. Factors that Influence Bleaching and Recovery

The research will begin with a comprehensive survey of 1998 bleaching patterns. The survey will be based on existing reports and analyses, including those prepared by the Global Coral Reef Monitoring Network (GCRMN), papers prepared for the 9th International Coral Reef Symposium in Bali, and material posted on Coral List. The purpose of this survey is to elaborate the determinants of differential susceptibility of corals to ENSO-related bleaching, mortality, and recovery, as outlined above.

2. Study Site Selection and Monitoring Methodology

Factors identified through the initial survey will be developed into a set of criteria or hypothesis that can be tested at project study sites. The site selection criteria should capture the range of variables likely to explain differential susceptibility to ENSO-related bleaching on coral reefs and the conditions favorable to coral recruitment and recovery. In addition to bleaching susceptibility and recovery criteria, other project design considerations will be addressed as part of study site selection to ensure comparability among sites, including geographic range, existing monitoring arrangements, management effectiveness (e.g., enforcement capabilities, control of impacts from destructive and upstream activities), and variability of context (e.g., reef type, depth, condition, etc.).

In considering the geographic range for the selection of sites, the advantages and disadvantages of a regional or a global focus will be taken into account. A global focus allows a wider range of specific conditions to be included, a larger number of linkages with other organizations and projects to be made (e.g., with the Coral

Reef Degradation in the Indian Ocean [CORDIO] project), and an increased chance of observing bleaching events in the near term. On the other hand, a global focus spreads effort and funds widely, which permits less site variety within a relatively small sample, less chance of a single bleaching event affecting all of the sites included in the project, and increases the complexity and costs of project management. To balance these concerns, it is our intention to focus on sites in Indonesia, the Philippines, Fiji, and the Western Pacific.

All study sites will have an existing or imminent monitoring program to reduce project expenses by building on existing activities, rather than initiating costly new programs. Also, for pragmatic reasons, sites are expected to have a strong TNC, WWF, or partner presence; however, the intention of this decision is not to be exclusive, and we will certainly consider collaboration with other interested parties.

A preliminary list of study site selection criteria includes:

- Wide variety of reef types: oceanic, continental, barrier, fringing, patch/pinnacle, atoll
- Varied and strong influence of wind/wave/current regimes
- Wide depth range
- Large tidal range
- Varied orientation: slope, sun/shade
- Natural physical-chemical stresses (e.g., salinity, exposure to air, turbidity)
- Existing monitoring program
- Effective management program

The research design will be finalized by a few key experts that will:

- Confirm patterns that should be investigated
- Review study site selection criteria and characteristics and identify 8-10 suitable study reefs

3. Identify Appropriate Parameters to Monitor and Define Standard Monitoring Methods

Preliminary MPA Selection, Design, and Management Principles Field staff at the selected study sites will determine the extent to which current analytical and monitoring efforts include the information needed by the project, and what (if any) changes would be required to carry out the requisite analysis and monitoring. If needed, in-depth analysis will be conducted at each study site to describe patterns of bleaching and mortality from the 1998 (or last major) bleaching event and to identify their likely determinants. From this analysis, and the initial literature and field survey, tentative MPA selection, design and management principles, reflecting the characteristics most conducive to coral survival and recovery from bleaching, will be drafted. These principles will be circulated to a number of scientists and management practitioners, and revised according to the comments received.

4. Monitoring Field staff at each study site will monitor the rate and nature of recovery from the 1998 bleaching, according to the parameters identified in the selection criteria. While the frequency and method of monitoring will be determined in the final research design, we expect, for planning purposes, to monitor each site once per year over five years. To the extent possible, this monitoring will be included in regular activities already being carried out at existing project sites. Annual reports of monitoring results across the study sites, (and for the sake of comparison, at specific sites of comparable size in the Great Barrier and Meso-American Barrier Reefs), will be produced and widely disseminated for comment.

5. Revalidation and Promulgation
A detailed analysis of the patterns of coral bleaching, survival and mortality during the next major ENSO-related bleaching event will be conducted at each study site. On the basis of these analyses, a determination will be made as to the extent the preliminary management principles were validated by this new bleaching event. If they prove to be generally robust, the principles would then be revised, as needed, and disseminated widely for use as guidelines for marine protected area managers throughout the Asia Pacific region and worldwide.

Conclusions

Measures to mitigate the impact of ENSO-related mass coral bleaching need to be significant to address the scale of it witnessed following the 1997-1998 El Niño. A combination of rigorous protection of areas where corals show greater resilience to bleaching, along with measures to enhance natural recovery of adjacent areas, where corals are more susceptible to bleaching and related mortality, could provide a solution. As a start, new science-based, empirically tested principles are needed to guide the selection, design and management of MPAs so that they can maximize coral survival and recovery from ENSO-related bleaching events.

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CORAL BLEACHING AND MORTALITY: A CALL FOR SCIENCE-POLICY SYMBIOSIS

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ABSTRACT

The geographic extent and severity of the mass coral bleaching and mortality events in 1998 served as a wake-up call to scientists and policymakers alike. This global environmental catastrophe appears to have been a consequence of a steadily rising baseline of marine temperatures and regionally specific El Niño and La Niña events. Coral reef scientists and monitoring programs played a key role in the timely tracking of the bleaching and mortality, identification of the links to climate events, and subsequent analysis of the implications and impacts of the events for coral reef ecosystems. The involvement of scientists in the U.S. Coral Reef Task Force and international policy forums, such as the International Coral Reef Initiative (ICRI) and Convention on Biological Diversity (CBD), helped craft an international policy consensus on the causes and consequences of the coral bleaching problem. We review the lessons learned from the U.S. perspective in this collaboration among monitoring programs, scientists and policymakers—what helps or hinders incorporation of science into a successful policy consensus. We also identify several scientific questions, the answers to which will facilitate turning the policy consensus on climate change and coral bleaching into action. In particular, we highlight the need for science to support local action to address anthropogenic stressors that already place reefs at risk, as well as the need for global action in reducing greenhouse gas emis-

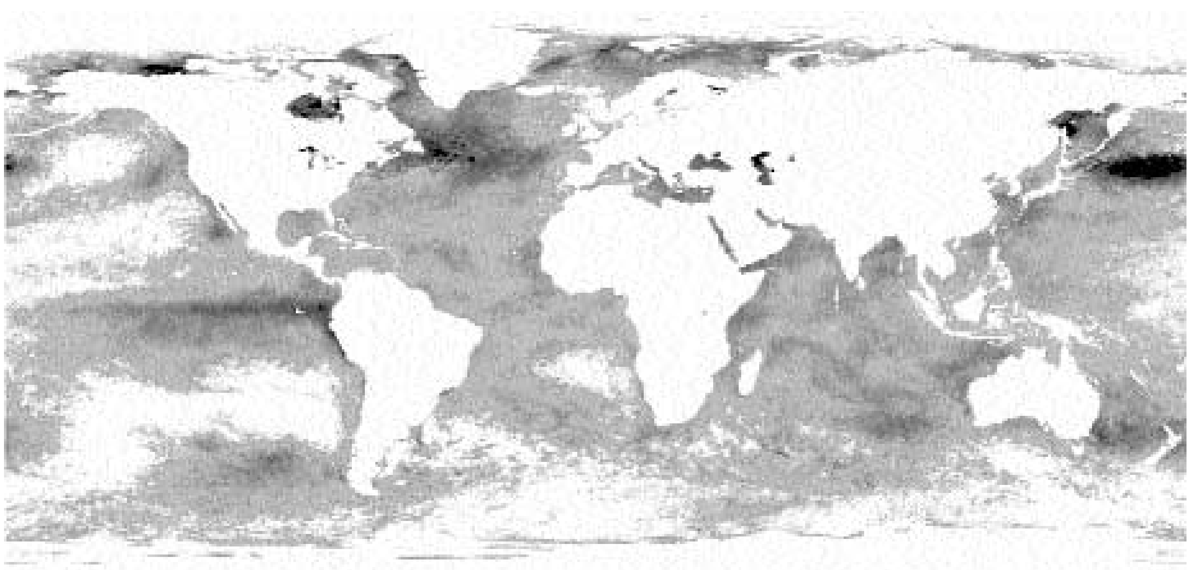

Figure 1. Compilation of maximum sea surface temperature (SST) exceeding the warmest expected values of the year for all of 1998. Grey areas show where SSTs exceeded this expected maximum yearly level by +1-2 deg C; darker areas: by as much as 3 deg C. Data from Pathfinder SSTs with 9-km resolution. (NOAA 2000).

Table 1. Timeline for actions taken in response to the mass coral bleaching and mortality events of 1998.

Date	***International Policy Response***	***Science Input to Policy***	***Monitoring***	***U.S. Policy Response***
Winter 97/98			NOAA satellites & bleaching reports	
March/April 1998			Worst coral bleaching mortality in the Indian Ocean	
May 1998	CBD COP-4 Calls for SBSTTA & UNFCCC Action		Severe bleaching in Indonesia	U.S. strongly supports CBD Resolution
Summer 1998			Reef Check 98 Bleaching in W. Pacific & Caribbean	E.O. 13089 Creates U.S. Coral Reef Task Force (CRTF)
Fall 1998		ISRS & ITMEMS Bleaching Statements		1st CRTF Meeting
December 1998				U.S. State Dept. Science Briefings on Bleaching
March 1999		Wilkinson et al. 1999		State Dept. Report to CRTF Adopted
Summer 1999		NOAA/ICLARM Remote Sensing Workshop Hoegh-Guldberg 1999	Reef Check 1999	
Fall 1999	ICRI Resolution on Bleaching	CBD Bleaching Experts' Meeting		Begin development of U.S. National Monitoring
Jan/Feb 2000	CBD SBSTTA-5 Coral Resolution			*U.S. National Action Plan to Conserve Coral Reefs*
May 2000	CBD COP-5 Resolution			
Fall 2000	CBD begins consultations	9th ICRS *Status of the Reefs 2000*		
Next Steps	UN FCCC Action ? GEF Funding ?		GCRMN Implementation	U.S. Action?

sions.

INTRODUCTION

In 1998, coral reef scientists, managers and government officials witnessed, in real time, a coral bleaching and mortality event that was unprecedented in geographic extent and severity. An estimated 16 percent of the world's coral reefs appear to have been destroyed in 1998 (Wilkinson, 2000). The repercussions of the event have impacted biological, social, and economic systems, increasing the threats to many coastal and small island communities in developing nations (Hoegh-Guldberg, 1999; Wilkinson et al., 1999; Goreau et al., 2000; Reaser et al., 2000; Wilkinson, 2000).

Thankfully, many individuals, scientific organizations, and governments around the world became concerned and began to take action, even before the bleaching ended. There is still much to be done to address the on-the-ground consequence of the event and to mitigate for such events in the future. However, scientists and government officials have already put in place many of the international policies needed to support these actions.

In this paper, we will briefly review the role that science has played informing policy recommendations on coral bleaching and mortality since the 1998 events. We discuss lessons learned from this campaign—what works for, and what often stops, scientists in their efforts to influence the policymaking community. We also discuss opportunities for the scientific community to engage in further policy development and implementation.

Admittedly, our paper is largely from the U.S. perspective. We hope that other countries will share their own experiences and the lessons they have learned. The work of their scientists and policymakers was at least as important in bringing the international policy process together.

The Story: From Environmental Impact to Policy Consensus

Scientists from the National Oceanic and Atmospheric Administration (NOAA) who were monitoring sea surface temperatures (SST) during the major 1997-98 El Niño event became concerned about coral bleaching, even before the mass event was reported. Their satellite imagery showed SST rising well above normal summer mean temperatures in tropical regions around the world. (Fig.1.) On-site observations and NOAA SST records from North Atlantic and Caribbean reef locations show a significant correlation between all large-scale bleaching events and high SSTs (Gleeson and Strong, 1995; Goreau and Hayes, 1994; Strong et al., 1998).

Marine biologists and volunteer divers, alerted to the possibility of bleaching through NOAA Websites and the Global Coral Reef Monitoring Network (GCRMN), began field surveys throughout the coral reef regions of the world. It quickly became apparent that NOAA's concerns were warranted. Where the waters were anomalously warm, reef-building corals were bleaching.

Marine biologists and policymakers alike began to ask, "Was this a one-time catastrophe, a random event, from which most reefs would recover? Was the warm water caused by El Niño, a predictable regional disturbance to which reefs might adapt? Was it more than El Niño alone—perhaps El Niño driven by global warming? And, if this was a massive event tied to global climate change, was it the signal of more to come… and worse?" Table 1. summarizes subsequent actions taken by the scientific and policymaking communities.

In May of 1998, East African and Indian Ocean countries that were experiencing severe impacts of coral bleaching, raised such questions at the 4th meeting of the Conference of the Parties to the Convention on Biological Diversity (CBD). Other countries (e.g., the U.S. and Jamaica) strongly echoed their concern. As a result, the CBD directed its Subsidiary Body on Scientific, Technical, and Technological Advice (SBSTTA) to analyze the phenomenon, and asked the United Nations Framework Convention on Climate Change

(UNFCCC) to urgently address this issue.

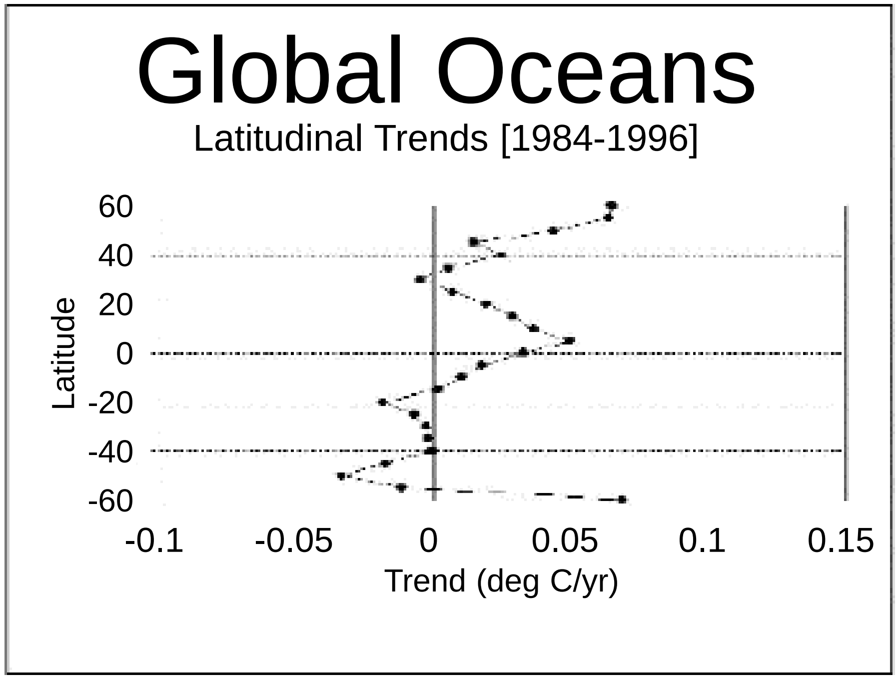

Figure 2. Graph shows global sea surface temperature trends at different latitudes from 1984 to 1996 derived from Advanced Very High Resolution Radiometer (AVHRR) satellite observations (Strong *et al.* 2000). Even omitting the record breaking warm El Niño years of 1997 and 1998, there are clear warming trends, between latitudes 10° South and 25° North, prime regions for coral reef growth.

In the U.S., in June of 1998, President Clinton announced an Executive Order on Coral Reef Protection as part of the Year of the Ocean. Although not specifically a response to the global bleaching event, the Executive Order set up a U.S. Coral Reef Task Force, which provided a nexus for the U.S. policy and implementation response for coral reef conservation, including coral bleaching.

Through the summer of 1998, reports of coral bleaching and mortality came in from at least 60 countries and island nations in the Pacific, the Indian Ocean, the Red Sea, the Persian Gulf and the Caribbean. Data collated by Reef Check and GCRMN showed the mass bleaching and coral mortality to be the most severe ever recorded (Wilkinson et al., 1999; Wilkinson, 2000). This monitoring catalyzed action by coral reef scientists and managers. The International Society for Reef Studies (ISRS) and the first International Tropical Marine Ecosystems Management Symposium (ITMEMS) adopted statements that summarized their collective knowledge of the event and called for urgent attention from the policymaking community.

The U.S. Coral Reef Task Force and U.S. Department of State recognized that the mass coral bleaching and mortality event had powerful implications for coastal communities around the world and for climate change and natural resource policy. Over the Christmas holidays of 1998, the Department of State's Deputy Assistant Secretary, Rafe Pomerance, called coral reef experts to the Department for an urgent briefing of government officials on the biological and climatological aspects of the coral bleaching events. Sufficiently alarmed by their reports and the possible links to climate change, Mr. Pomerance requested that State Department's biodiversity scientists (Peter Thomas and Jamie Reaser) investigate the breadth of scientific findings and policy implications and prepare a report. After analyzing the literature on atmospheric and oceanographic modeling, as well as the biology of coral bleaching, Drs. Thomas and Reaser consulted with top government and academic scientists from around the world to analyze the complex factors involved in the 1998 event and in the overall atmospheric and ocean warming trends of past decades.

The Department of State report (Pomerance et al., 1999), released in March of 1999 to the President's U.S. Coral Reef Task Force, concluded that the severity and extent of the 1998 event cannot be explained by El Niño alone. The geographic extent, increasing frequency, and regional severity of mass bleaching events are a likely consequence of a decades-long rise of baseline marine temperatures (Fig. 2.), perhaps driven by anthropogenic global warming. The report warned that, if warming trends continue, coral bleaching events may become more frequent and severe, exposing reefs to an increasingly hostile environment. After careful consideration of the Department of State's report, the U.S. Coral Reef Task Force passed a resolution concluding that "Biodiversity conservation can no longer be achieved without consideration of the global climate system." The Task Force urged U.S. agencies to address the impact of global climate change on the natural resources they manage.

In the summer of 1999, NOAA, in conjunction with the Institute for Coastal Living Aquatic Resource Management (ICLARM), hosted an international workshop on increasing the capacity of remote sensing technologies to detect and monitor coral bleaching and mortality, in order to make scientific findings rapidly available to policymakers. The U.S. joined with France, Sweden, and the World Conservation Union (IUCN) to provide funds and organizational support to an International Experts Consultation on Coral Bleaching, convened by ICLARM in Manila in October 1999, under the auspices of the CBD. The recommendations from that consultation are shown in Appendix 1.

The U.S. then brought the Department of State report, resolutions from the U.S. Coral Reef Task Force, findings from the remote sensing meeting, as well as from the Experts Consultation, to its partners in the International Coral Reef Initiative (ICRI). ICRI passed two more resolutions. These were sent directly to the CBD and the UNFCCC. They called for adoption of the recommendations from the Experts Consultation, and immediate implementation from the policy communities.

In early 2000, SBSTTA considered the conclusions and recommendations put forth by the Experts Consultation. Presentations by NOAA scientists and non-governmental organizations helped further inform SBSTTA, which accepted the findings from the Experts Consultation, concluding “that there is significant evidence that climate change is a primary cause of the recent and severe extensive coral bleaching.” SBSTTA then called for the Parties to the Framework Convention on Climate Change and other relevant conventions to join with the CBD in taking action.

In May 2000, the Conference of the Parties (COP) to the CBD fully accepted SBSTTA’s recommendation. Coral bleaching will have a specific focus under its Work Program for Marine and Coastal Biodiversity (www.biodiv.org). This decision is widely regarded as being one of the most universally supported and scientifically well-informed decisions under the Convention to date. Hopefully, it will translate into considerably more resources being available to help communities already devastated by bleaching, to help managers implement response measures, and to help scientists find answers to the many outstanding unknowns.

What Works: Lessons for Scientists Working with Policymakers

Not every environmental crisis moves from the scientific community to international policy decision this fast. In fact, earlier severe bleaching events failed to attract this level of concern or attention from the international policy community. Risk (1999) noted that both the major coral reef monitoring techniques and the major stresses to coral reefs, other than climate change, have been known for more than 20 years, yet no country has adequately implemented a detection-identification-remediation protocol.

The response to the 1998 coral bleaching clearly illustrates that scientists can have a substantial impact on international policy when they are willing to bring scientific information directly into the halls of government and to deliver it in a way that is meaningful for policymakers. We learned several lessons about what worked. These lessons will need to be applied in order to guide the coral bleaching decisions to practical implementation. Because these lessons are broadly applicable, there are opportunities to apply them to the other factors that threaten reefs as well.

Go to the policymakers.

Scientists are most effective at communicating with policymakers when they are willing to understand and work within the policy process. Often, this means participating in policy-directed meetings and building strong relationships with the staff that the policymaker depends on for his or her information and direction. For example, U.S. scientists took advantage of the Christmas briefing in 1998 to become part of an intense scientific and policy effort which has put the bleaching issue front and center.

Recognize and respond to the different objectives and information needs of the scientific and policy communities.

Scientists and policymakers are distinct creatures. Individuals in these fields tend to process information and respond to experiences differently. These differences often make communication between the two communities a substantial challenge. A scientist who can "step into the shoes" of a policymaker can understand specifically what that policymaker needs and how best to deliver it from the scientific community. For example, in support of the State Department paper, scientists from a number of disciplines were able to look past their own area of expertise to help craft a paper that was both scientifically accurate and as ambitious as possible in describing the links between coral bleaching events and global climate change. Examples of differences in the science and policymaking communities include the following (Reaser, 1999; Reaser, 2001):

Perspective Scientists tend to be specialists. Their careers are made by knowing a lot about something specific. Policymakers on the other hand are generalists. They must be able to converse generally about a broad and ever-changing range of topics.

Motivation Scientists are motivated to understand the structure and function of what they study. Their work is a step-wise progression toward identifying and understanding a problem. Policymakers are more likely to be

U.S. Coral Reef Task Force: The U.S. Coral Reef Task Force was established by Executive Order of the President in June 1998. The Task Force is co-chaired by the Secretaries of the Departments of Commerce and Interior. The Secretaries and Administrators of eleven federal agencies and the Governors of the seven states and territories with coral reef resource managers cooperatively launched this effort to help save U.S. and international coral reefs. This collaborative body represents the major governmental stewards for the marine and coastal resources of the United States and plays a primary role in guiding the conservation of coral reef ecosystems. It also includes the Department of State and U.S. Agency for International Development, the major international policy and development assistance arms of the U.S. government. The Task Force serves as a major focus for bringing together science, policy and management of U.S. reefs. In March of 2000, the U.S. Coral Reef Task Force unveiled *The National Action Plan to Conserve Coral Reefs* (http://coralreef.gov).

motivated to get away from problems. It is their job to implement solutions quickly and keep their constituents out of less than desirable situations.

Timelines Scientists routinely complain that granting cycles are too short, that three or five years on one project isn't enough time to fully clarify the questions that they want to answer. In contrast, a policymaker must respond to the crisis of the moment, often counting time to closure on an issue in hours and days.

Confidence Limits Scientists typically believe that questions have provable answers and that, ultimately, it is this proof on which the direction and certainty of anyone's decisions should be based. Because most policymakers are not themselves scientists, they have to turn to individuals whose peers recognize them as an "expert" in their scientific field. Policymakers must trust these experts to deliver the "truth" and accept their information as "fact."

Core Question Ultimately, scientists are idealists, asking, "What is the truth"? Policymakers are pragmatists, who seek workable solutions by considering numerous perspectives.

Recognize and respond to the differences in scientific and policy process.
Scientists and policymakers reach their outcomes via different means. Conservation biologist Gary Meffe (1998) writes, "I offer a few personal observations regarding the policy process: it is messy, confusing, slow, painful, frustrating, illogical, and fraught with human foibles and biases." In contrast, he sees the scientific process as a logical framework of testing and objective interpretation.

In order to move quickly away from the crises of the moment and find a solution that will work, policymakers must survey relevant information, rapidly evaluate options, constantly monitor the opinions and responses of colleagues and constituents, and weigh the major possible outcomes of their decisions. Often, the objective of the decision is changing rapidly, as are the opinions and responses of those involved in the process. Because the policymaking process is often a cornucopia of moving targets, it is not surprising that scientists find intervening effectively on a specific issue a real challenge.

Neither policymakers, nor their staff dedicate their time to paging through scientific journals. More likely, the staff search out information on the Internet or place calls to dependable "experts." These dependable experts are scientists who are effective at educating policymakers because they recognize that timing and packaging are at least as important as informational content. Policymakers need rapid access to the bottom line in language that is appropriate for the policymaking community. A policymaker's position is built on "take-home messages" that offer a general direction for response and a specific, practical, course of action.

Nongovernmental organizations (NGOs) have increasingly begun to play roles as interpreters of science and interlocutors with the policymaking process. They often have connections with policymakers and can be powerful allies of the scientific community in getting the message across. NGOs have their own diverse array of objectives, however, and it is important for the scientific community to ensure that the integrity of the science is maintained.

Think and act long-term.
ICRI, GCRMN, and ISRS have become viable institutions, because a committed international community of governments, scientists, and NGOs has supported and used them to draw attention to the plight of reefs, and to build the connections between scientific understanding and concerted action for their protection and sustainable use. While money has been tight, and the participation of individual governments and other partners has had its ups and downs, persistence has paid off.

What Stops Us: Barriers to the Effective Integration of Science and Policy in Coral Reef Conservation

Scientists interested in providing advice to policy formulation must overcome a number of barriers (Reaser, 1999). Coral reef scientists who expect scientific evidence to drive and prevail exclusively in the policy process will not make effective progress. Policymakers must consider social and economic variables, as well as science-based information. Scientists who make the prolonged effort to work within the policy process may, in turn, suffer the "edge effects" of a career interfacing two disciplines, each measuringe success very differently.

Policymakers also have problems incorporating science into their deliberations. Chief among them is lack of information in a usable form. Policymakers need to know to what extent results may be generalized from a local basis to a national, regional or global one. The information must also be timely. This is why coordinated monitoring and rapid reporting of results are so important. The linkage of real-time satellite observations of sea surface temperatures with researcher responses through NOAA's Coral-Listserve provided a unique example of how such a system could be effective. Unfortunately, as noted by Risk (1999), current reef monitoring programs are generally uncoordinated and do not feed directly into stress-identification and mitigation programs.

Once policymaking agencies have received information, many have inadequate in-house expertise to respond. Policymakers are often extremely bright individuals, but they are seldom trained in weighing scientific information. The Department of State and several other agencies have begun to address this need by hiring scientists or bringing in promising researchers on fellowships. On a larger scale, countries or international organizations often lack mechanisms to accept scientific input, process it into policy, and oversee its implementation. Beginning in 1998, the U.S. Coral Reef Task Force has provided a such a mechanism to meet this need in the United States (see box). Internationally, the development of ICRI and GCRMN formed a major mechanism through which information on the bleaching event was brought to the attention of policymakers. It remains to be seen whether the CBD can develop mechanisms to incorporate science effectively into action strategies to respond to crises such as this one.

Finally, acting upon scientific information requires an act of will by the policymaker. Beyond the legitimate trade-offs between environmental objectives and other political and economic objectives, it is often considered easier to go with the status quo. Although financial resources will always be a constraint, the true test of policy priorities lies in how a government or international agency is willing to use existing resources.

Policy Consensus versus Policy Implementation

The policy process has two major aspects—development of initial consensus and translating policy into implementation. In the case of coral bleaching, it appears that consensus building has been successful. But this is not enough. Particularly in the international community, there is a tendency to pat ourselves on the back after we get "Resolution UNEP/CBD/COP5/ . . . " and go on to the next crisis of the moment.

With regard to climate change and coral reefs, several questions remain:

- How will the CBD and the Global Environment Facility "include coral bleaching in their work program"? At the 9th International Coral Reef Symposium, the CBD Secretariat began informal consultations with representatives of international organizations to prepare a draft work program.
- How will the U.S. Coral Reef Task Force follow-up on its resolutions?
- How will the UNFCCC respond?
- Ultimately, the biggest question is, "How will countries change their behavior across relevant sectors—particularly those related to the reduction of greenhouse gas emissions?"

While the magnitude and imminent nature of the potential impact to biodiversity on coral reefs has certainly still not been fully grasped by policymakers in the U.S. or the UNFCCC, the coral reef scientific community has now given individuals, both within government and without, a strong, scientifically sound message, and a solid internationally agreed-upon platform with which to work in continuing to raise awareness of this alarming phenomenon.

Future Opportunities for Engagement

The issue of coral bleaching has not yet come full circle. The scientists and managers that first raised the alarm do not yet have all the resources or the knowledge they need to ensure the protection or restoration of vulnerable reef systems. Yet, some very heartening policy decisions have been made, though there is considerable work ahead to ensure that they are adequately implemented. The scientific community can be a part of the process that closes the circle. If our ability to document the 1998 bleaching event in real time and the remarkable willingness of policymakers to accept the need for action is any indication, the opportunities for scientists to inform policy and engage in implementation are real.

Here are a few recommendations for scientists willing to engage in the policy process:

Look for opportunities to support monitoring efforts.
The experience of the 1998 coral bleaching event highlighted the importance of monitoring in providing a more synoptic view of problems, needed by policymakers. Be willing to become involved in long-term efforts beyond your own study sites and issues.

Educate yourself on the policymaking process and stay informed.

Become an active participant in ICRI. ICRI is a voluntary, broad-based partnership of governments, NGOs, international organizations and scientists. Twice a year the ICRI partners gather and report on global developments in policy and projects directed at the conservation of coral reefs (www.environnement.gouv.fr/icri).

Appendix 1. Results of the CBD Expert Consultation on Coral Bleaching.

Issue	Response
Information-gathering	
Our ability to adequately project, and thus mitigate, the impacts of global warming on coral reef ecosystems and the human communities which depend upon coral reef services is limited by the paucity of information on: (a) The taxonomic, genetic, physiological, spatial, and temporal factors governing the responses of corals, zooxanthellae, the coral-zooxanthellae system, and other coral reef associated species to increases in sea surface temperature; (b) The role of coral reefs as critical habitat for marine species and natural resources for human communities; (c) The current status of coral-reef health and threats to coral reefs; and (d) The potential capacity of recovery of corals and resilience of the ecosystem after mass mortality.	(a) Implement and coordinate targeted research programs, including predictive modeling, that investigate: (1) the tolerance limits and adaptation capacity of coral reef species to acute and chronic increases in sea surface temperature; (2) the relationship among large scale coral bleaching events, global warming, and the more localized threats that already place reefs at risk; and (3) the frequency and extent of coral bleaching and mortality events, as well as their impacts on ecological, social and economic systems; (b) Implement and coordinate baseline assessments, long-term monitoring, and rapid response teams to measure the biological and meteorological variables relevant to coral bleaching, mortality and recovery, as well as the socioeconomic parameters associated with coral reef services. To this end, support and expand the Global Coral Reef Monitoring Network (GCRMN) and regional networks, and data repository and dissemination systems including ReefBase - the Global Coral Reef Database. Also, the current combined Sida SAREC and World Bank program on coral reef degradation in the Indian Ocean (CORDIO), as a response to the 1998 coral-bleaching event could be used as an example; (c) Develop a rapid response capability to document coral bleaching and mortality in developing countries and remote areas. This would involve the establishment of training programs, survey protocols, availability of expert advice, and the establishment of a contingency fund or rapid release of special project funding; (d) Encourage and support countries in the development and dissemination of status of the reefs reports and case studies on the occurrence and impacts of coral bleaching.
The remoteness of many coral reefs and the paucity of funding and personnel to support on-site assessments of coral reefs requires that remote-sensing technologies are developed and applied in the evaluation of coral bleaching events.	Extend the use of early warning systems for coral bleaching by (a) Enhancing current NOAA AVHRR HotSpot mapping by increasing resolution in targeted areas and carry out ground-truth validation exercises; (b) Encouraging space agencies and private entities to maintain deployment of relevant sensors and to initiate design and deployment of specialized technology for shallow oceans monitoring; and (c) Making the products of remote sensing readily accessible to coral reef scientists and mangers worldwide with a view to those scientists and managers that are based in developing countries.
Capacity-building	
There is a substantial lack of trained personnel to investigate the causes and consequences of coral bleaching events.	Support the training of and career opportunities for marine taxonomists, ecologists, and members of other relevant disciplines, particularly at the national and regional level.
Coral bleaching is a complex phenomenon. Understanding the causes and consequences of coral bleaching events requires the knowledge, skills, and technologies of a wide variety of disciplines. Any action aimed at addressing the issue should bear in mind the ecosystem approach, incorporating both the ecological and societal aspects of the problem.	Encourage and support multi-disciplinary approaches to coral reef research, monitoring, socioeconomics, and management.
Public awareness and education are required to build support for effective research, monitoring, and management programs, as well as policy measures.	Build stakeholder partnerships, community participation programs, and public education campaigns and information products that address the causes and consequences of coral bleaching.

Engage in the policymaking process.
The CBD (http://www.biodiv.org/) and the Ramsar Convention on Wetlands (http://www.ramsar.org/) represent two international agreements through which coral reef scientists and policymakers can work together to develop policies and initiate funding strategies to address the causes and consequences of coral bleaching. Both have mechanisms through which scientists can present their research findings and recommendations to policymakers.

NGOs have shown the ability to play key roles in bringing scientific expertise to policy and public consumption. For example, the seminal paper on coral reefs and climate change (Hoegh-Guldberg, 1999) was supported and distributed widely by Greenpeace International. The World Conservation Union (IUCN) helped fund the CBD Technical Experts' Consultation on Coral Bleaching. With the World Wide Fund for Nature (WWF) and other partners, the IUCN has prepared a timely follow-on document on the management of bleached and severely damaged reefs (Westmacott et al., 2000; Wells et al., this volume).

4. Identify relevant policymaking staff and share information with them directly.
Policymakers don't have ready access to scientific journals, nor do they typically attend scientific meetings. Make yourself and your expertise known to the policymakers that represent your government at international negotiations. Give them copies of your publications, preferably with summaries written for non-experts.

5. Summarize your research findings and policy implications on the World Wide Web.
Many policymakers and their support staff now turn to the World Wide Web. They need information rapidly and in a format that is understandable to them. Create or find a website where you can regularly summarize your research findings and include an assessment of the key points that are relevant for policy decisionmaking. Make sure to include your contact information. The NOAA Coral Health and Monitoring Program website provides links to a number of excellent models (http://coral.aoml.noaa.gov/index.html). Note that text-only websites are often the most accessible for developing country policymakers.

6. Work with the ISRS and other scientific bodies.
Scientists can be a very powerful constituency when they act collectively.
The ISRS (http://www.uncwil.edu/isrs/), to the best of our knowledge, was the only scientific society to adopt a statement on coral bleaching. This statement, made by a well-respected body of experts, had a significant influence on the U.S. policy process and probably many others as well.

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