Coral Bleaching: Causes, Consequences and Response

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

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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"

Edited by Heidi Z. Schuttenberg

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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:

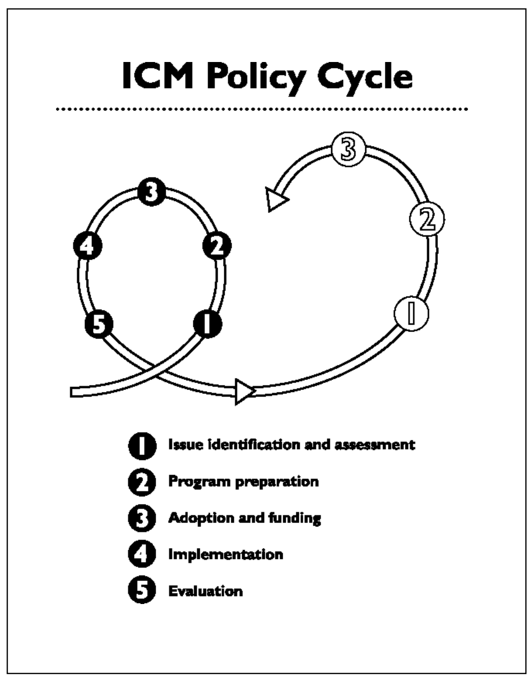
- Mass coral bleaching is one of a number of stresses that cumulatively threaten coral reef ecosystems and must be addressed within this larger context.
- Management can be undertaken in the absence of complete scientific understanding of the specific causes and consequences of mass coral bleaching and 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.)

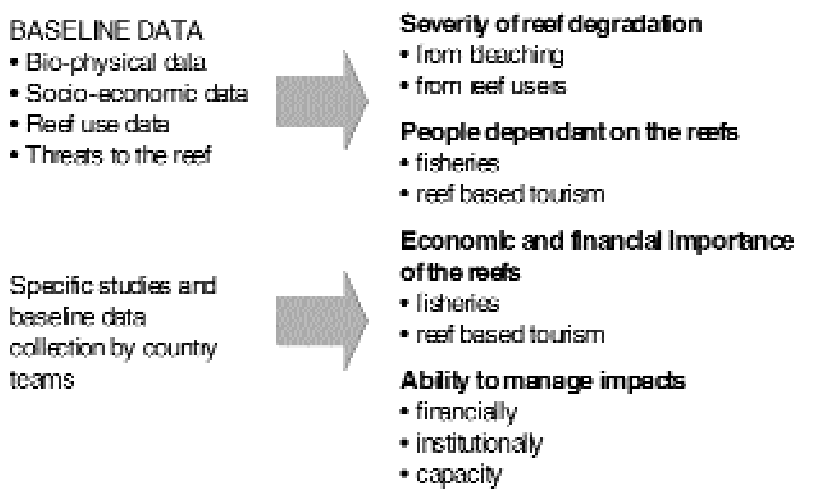


Figure 1. A series of different assessments and case studies were used to formulate the overall assessment of the impact of the bleaching on tourism & fisheries and as a whole.

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.

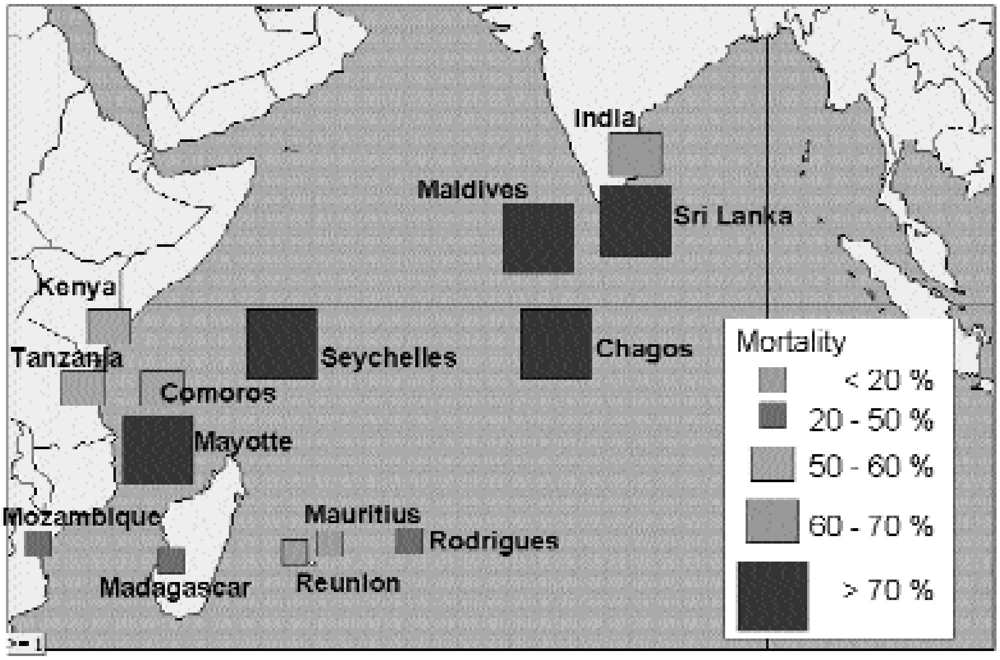


Figure 2. Coral Mortality in the Indian Ocean Resulting from the 1998 Coral Bleaching Event

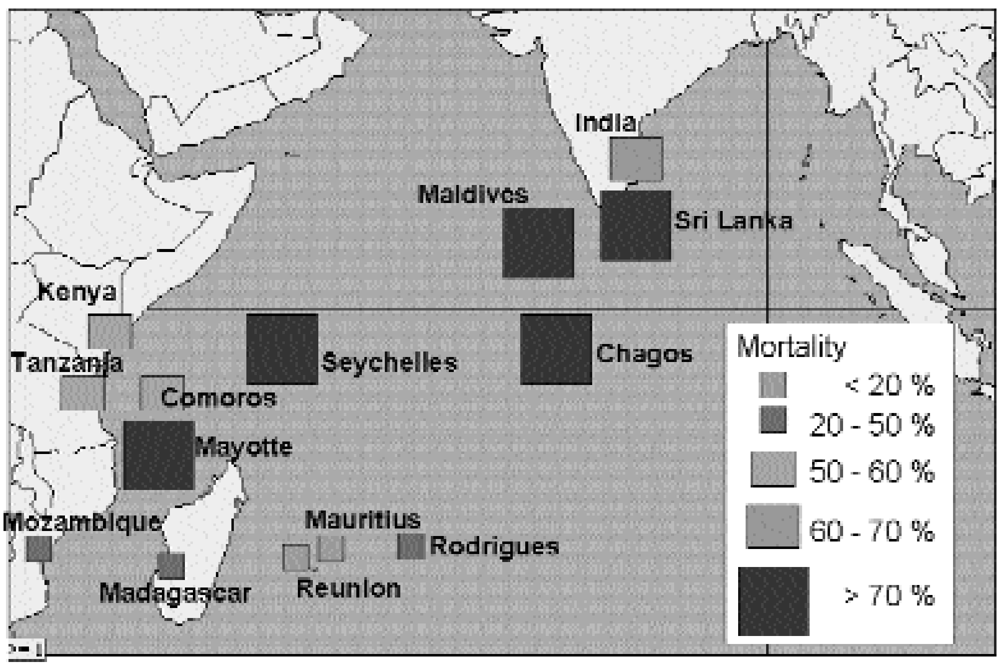


Figure 3. Reefs at Risk from Human Activities in the Indian Ocean

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.

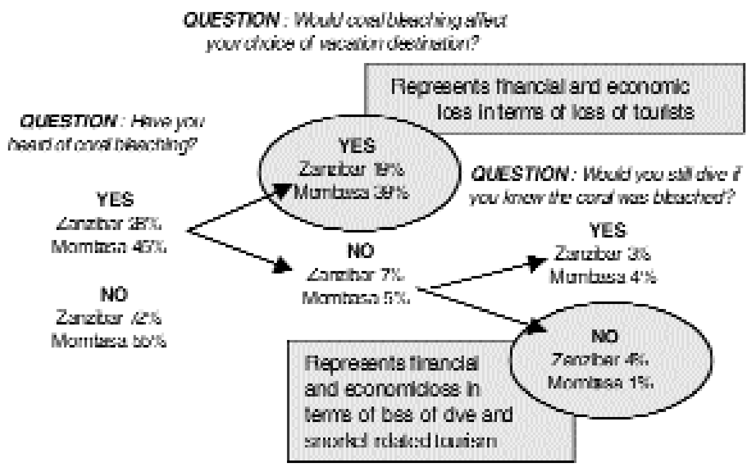
Potential Impacts of Coral Bleaching on Reef-based Tourism

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

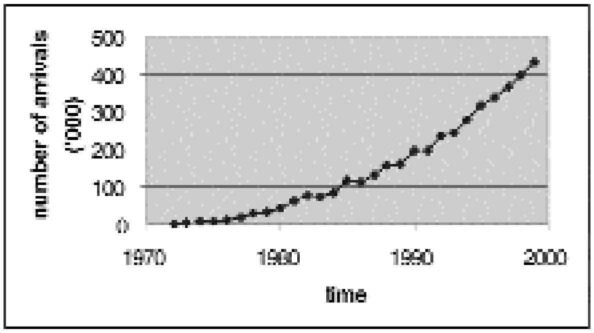


Figure 5. Annual Tourist Arrivals to Maldives Since 1972
(Source: Maldives Ministry of Tourism [1997, 2000])

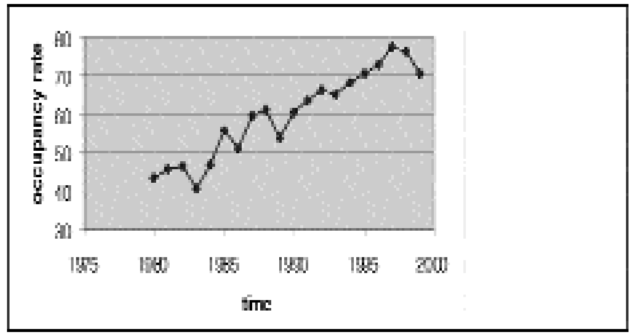


Figure 6. Annual Occupancy Rate in the Maldives Since 1980

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

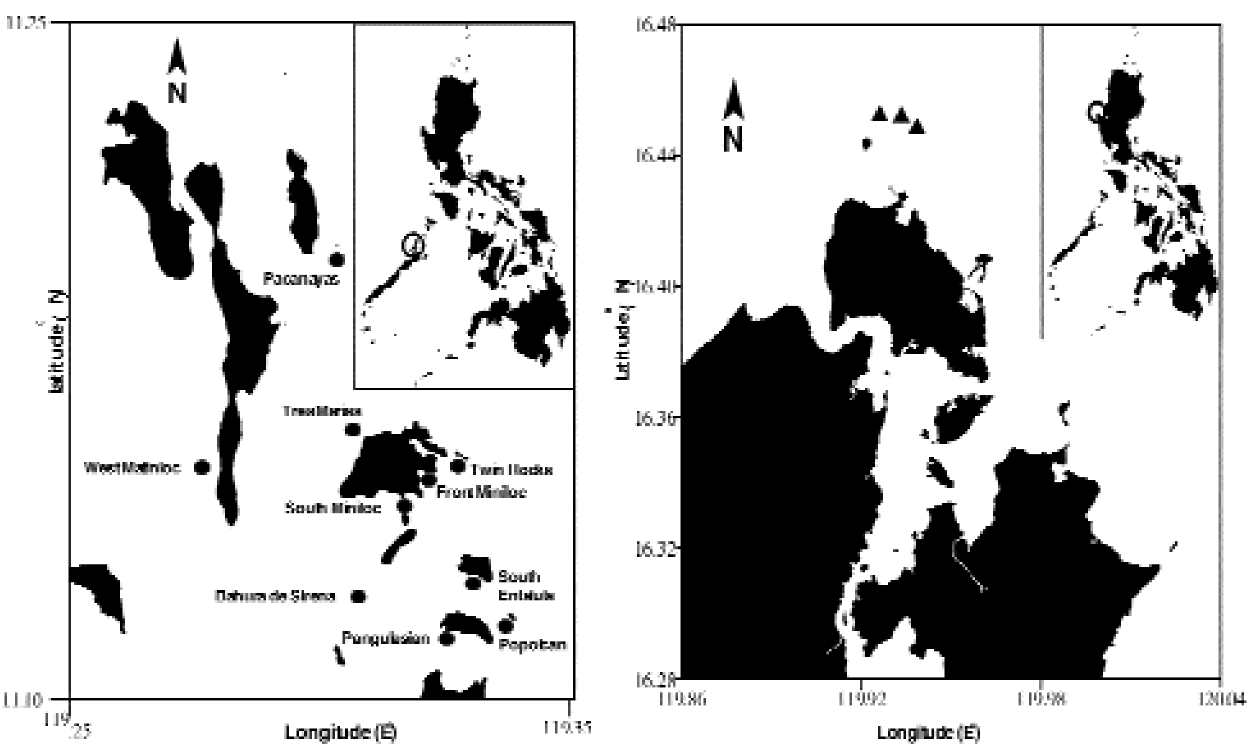
This investigation is the first socioeconomic evaluation of the impact of the 1998 coral bleaching event on the fisheries and tourism industry in the Philippines. Similar works (e.g., Wilkinson et al., 1999, Westmacott et al., 2000) have been undertaken in the Indian Ocean. While there are many possible 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, northwestern 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).

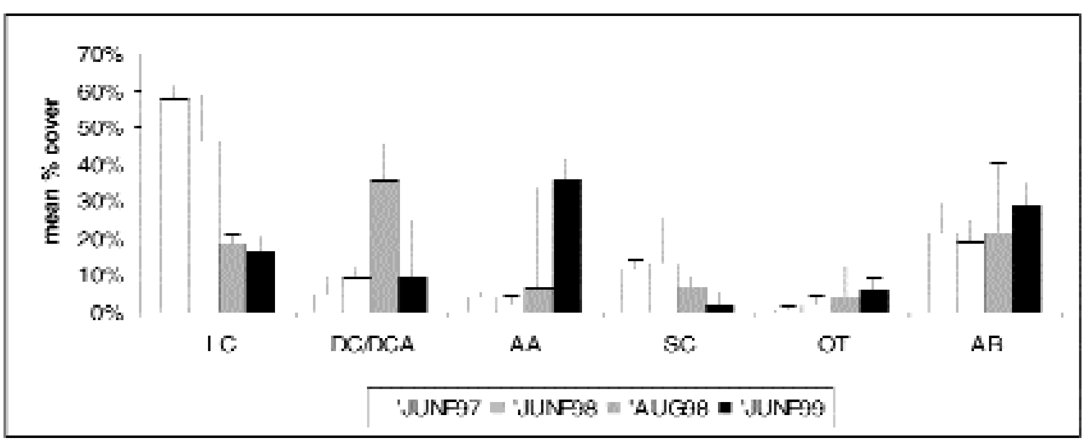
Methods

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.

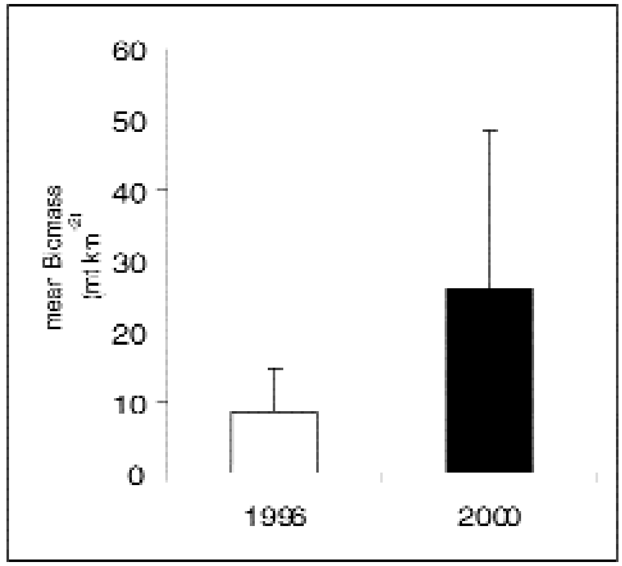


Figure 3. Mean Reef Fish Biomass (mt km^2) for All Sites in El Nido Pre- (1996) and Post- (2000) Bleaching

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

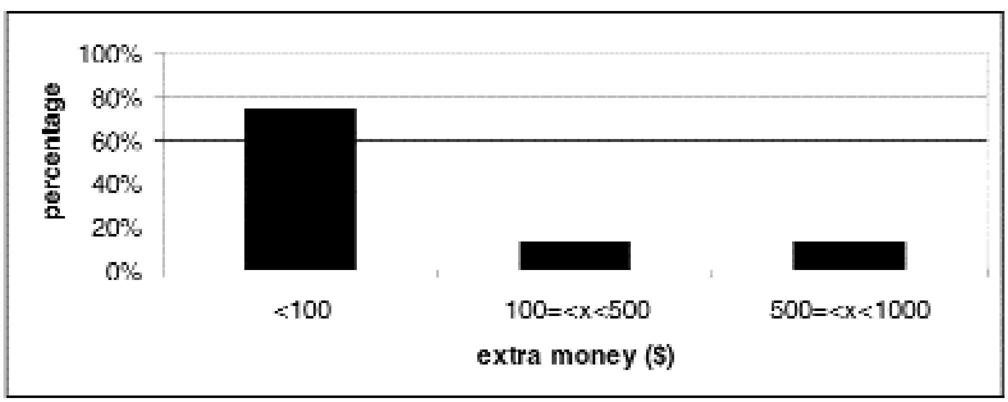
	Annual Loss to Local Economy	NPV Permanent *3% discount rate*	NPV Permanent *9% discount rate*	NPV Temporary *3% discount rate*	NPV Temporary *9% discount rate*
Budget tourists	10	179	99	49	40
Resort tourists	1500	26,815	14,893	7,349	5971
Total losses	1510	26,994	14,992	7398	6010

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

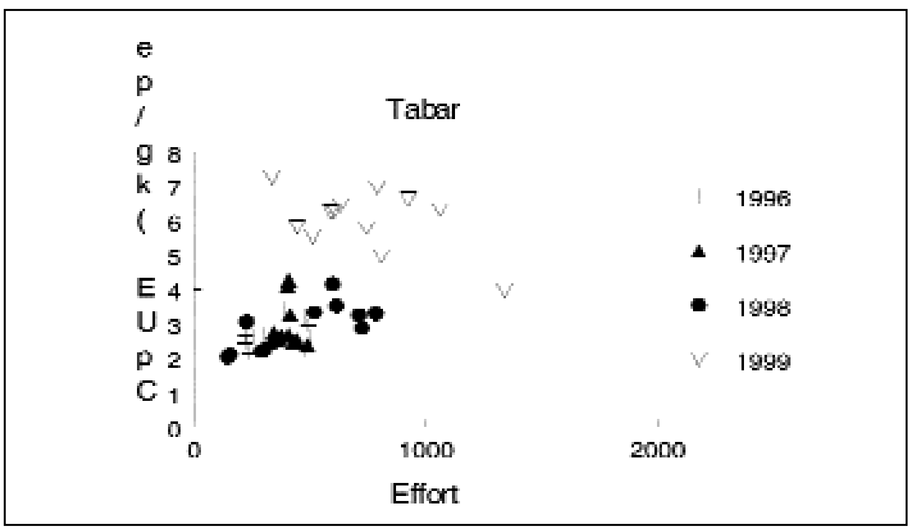
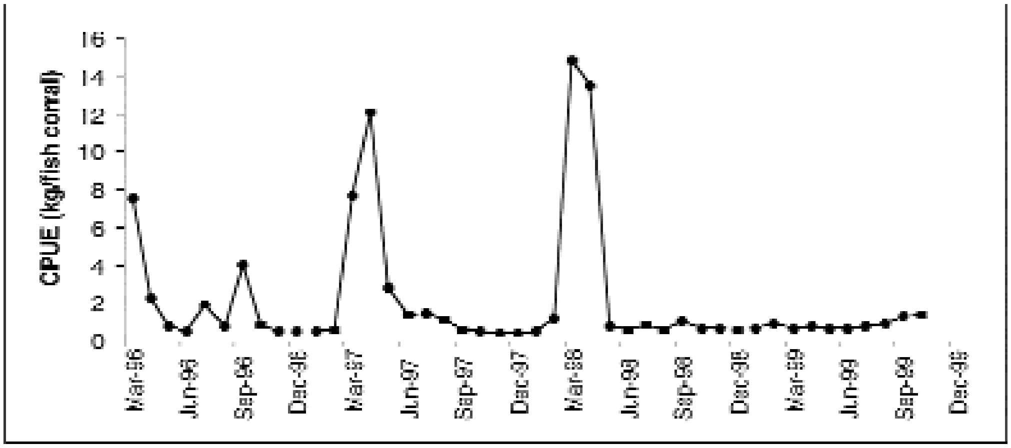


Figure 5. Effort and CPUE for *Tabar (gill-net operated while pounding on the water surface to scare fish)* from 1996-1999

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]
Basniq	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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