FIRST DRAFT FOR COMMENT

PREPARING MARINE PROTECTED AREAS TO SURVIVE GLOBAL CHANGE
Additional Guidelines To Address Coral Bleaching

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Please note: all persons contributing comments to these draft guidelines will be specifically notes in the acknowledgements to the final document.

BACKGROUND

In the face of rampant reef destruction and the staggering impacts of such large-scale unmanageable threats as climate-related thermal bleaching, people are beginning to ask whether there is anything we can do to conserve our coral reefs. The greater skeptics among these even venture to ask "why bother trying to conserve coral reefs when events that are beyond our control will undermine our best efforts?" The answer to this question would certainly be "we probably shouldn't bother trying if we keep doing what we have always done. However, if we can adapt our approaches to the times, we should never stop trying!"

The good news is that for every statistic that describes the corals lost to bleaching, there is the complementary statistic that indicates how much coral survives. This largely unspoken statistic gives us hope; and if we can understand the survival factors underlying it, we will have the means to adjust our approaches to coral reef conservation so that they build on survival, despite these daunting global trends.

This document is about moving beyond hope. It is about looking at what survives a major bleaching event, and about building that into our coral reef conservation programs. It is a piece of a larger initiative that originated one sunset in Komodo National Park in Indonesia and had its formal beginnings at the 9th Coral Reef Symposium in October 2000. There, the concept was first presented for discussion that certain environmental factors seem to help some coral communities resist bleaching and that these could be identified and used to influence to how we select, design and manage marine protected areas.

Encouraged by the favorable response this presentation received at the symposium, The Nature Conservancy and World Wildlife Fund (US) convened a small working group in 2001 (Salm and Coles 2001). The participants, who collectively had considerable experience in relevant research and MPA management experience in all the major coral reef areas of the world, confirmed the concept that certain environmental factors favor survival and recovery of bleached corals and other organisms. They agreed on a list of factors that confer bleaching resistance (coral colonies that don't bleach or bleach but don't die) and resilience (reefs where colonies bleach and partially or wholly die, but the coral community recovers). Furthermore, the participants recommended that policy-makers and resource managers should include reefs containing these factors within MPA networks. Also stressed was the need to assist the recovery of bleached coral reefs by protecting them from siltation, pollution, overfishing, and other destructive practices.

The workshop participants outlined a a two-track approach for a global program to test and verify that environmental factors are effective in mitigating bleaching impacts. The goal of this global program is to maximize the protection of coral reefs in the face of expected increases in frequency and intensity of climate related bleaching events.

The first track includes worldwide assessments, research, and monitoring. These will be designed to provide solid scientific evidence to verify current information regarding the contribution of environmental factors to bleaching resistance and resilience. The reliability of these factors will be tested and applied to generate additional MPA selection criteria and design principles—the two primary components of the second track.

Simultaneously, through the second track, draft additional MPA selection criteria and design principles will be prepared and distributed globally for application, verification, and refinement. This document represents the first step in implementation of the second track. The target is to assimilate feedback from the two tracks and discuss these additional MPA criteria and principles at the 5th World Parks Congress, to be convened by IUCN World Commission on Protected Areas (WCPA) in mid-2003. A need for and structure of a global MPA practitioners support network to facilitate global application of the new selection criteria and design principles will also be discussed during the Congress. The IUCN WCPA will play a key role in this entire process.

Recognizing that areas resistant to bleaching are critical to the recovery and survival of coral communities that succumb to bleaching or other stresses, MPA managers should give these sites adequate protection so that they retain their effectiveness as sources of larvae to enable the recovery of affected areas. There is also value in increasing the probability of reef community recovery from bleaching and other stresses through replication of MPAs—the more MPAs there are, the greater the likelihood that significant components of these will survive to facilitate recovery of affected areas.

INTRODUCTION

Large-scale coral bleaching events have increased in intensity, frequency, and geographic distribution in the last two decades (Wilkinson 1998, 2000). The 1998 El Niño Southern Oscillation (ENSO) event and 1999 La Niña caused mass coral bleaching of unprecedented proportions worldwide and complete loss of live coral in some parts of the world (Goreau *et al*. 2000). We now recognize that climate-related bleaching events pose a serious global threat to coral reefs and need to be addressed by management and planning guidelines (Goreau *et al*. 2000, Westmacott *et al*. 2000, Salm *et al*. 2001). Furthermore, ENSO events are expected to occur with greater frequency and intensity over the coming decades, which calls for urgency in deployment of practical measures to mitigate their impacts on coral communities at sufficiently large scales to be effective (Salm *et al*. 2001).

Despite the widespread bleaching associated mortality of coral reef organisms, particularly that following the 1998 ENSO, it is rare for living corals to be completely eliminated from a section of reef. Even in the most severe cases, some coral communities appear to be more resistant (coral colonies don't bleach or bleach but don't die) or more resilient (the coral colonies bleach and partially or entirely die but the coral community recovers rapidly to its former state). A recent analysis of bleaching reports (Wilkinson 2000) indicates that there is a wide variability in intensity, species affected, depth, and geographic distribution, and how much mortality a bleaching event causes.

Patterns of bleaching-related mortality provide insights into the factors influencing the differential responses of coral communities to bleaching, which in turn provide opportunities for us to select and design MPAs to give adequate protection to coral communities shielded by these factors (Salm *et al*. 2001). The implication is, that in addition to selecting MPAs for the usual range of accepted criteria and managing them as we usually do to control specific threats, we would introduce additional criteria and design principles focused on survivability.

Building coral reef survivability based on patterns of resistance and resilience into our management strategies for MPAs is a new concept. Survivability has never been explicitly defined and listed as a criterion for MPA selection or in the principles for MPA design, nor has it been factored into large scale ecoregional planning. Yet the concept of survivability as described in this report will demonstrate that there are positive actions that we can take to counter the potentially devastating impacts of climate-related bleaching on coral reefs.

Although existing MPA selection criteria and design principles do not define specific management interventions to address emerging global threats such as climate related coral bleaching, they retain definite value. They help to define conservation objectives and targets, beginning the process to identify the threats to these, along with their sources or root causes, and to determine management strategies to address the threats. These criteria and principles provide the focus for coral reef conservation planning and – along with various approaches, such as community participation, co-management, and the like – provide the core strategies for effective MPA establishment.

For the global threats we need new approaches that complement our usual range of management actions and ensure that the areas we conserve are not only protected from the more immediate and manageable impacts, but also from the larger scale and unmanageable ones.

This document builds on the more usual complement of MPA selection criteria, design principles, and management guidelines (e.g., Salm *et al*. 2000) to present some draft additional ones aimed at enhancing the survival and recovery prospects for coral communities affected by ENSO-related bleaching. These additional criteria, principles, and guidelines are derived from concepts first presented at the International Coral Reef Symposium in 2000 (Salm *et al*. 2001) and expanded on in a subsequent workshop (Salm and Coles 2001, West 2001a,b).

SELECTION OF CORAL REEF MARINE PROTECTED AREAS

This section is intended to help MPA planners and managers to identify candidate coral reef conservation areas and to select from these ones that have good chances of resisting coral bleaching or recovering rapidly and fully from it.

Existing MPA selection criteria do not adequately address survivability. In fact, it is by and large tourism and pragmatic criteria (see following section) that historically have driven the selection of smaller MPAs or of the different zones within larger ones. Fisheries replenishment has played an increasingly dominant role in MPA selection and design over the past decade. Tourism is an important source of revenue in most developing countries and so is given high priority; fisheries is more a result of the will of local people during these more enlightened times of meaningful community participation in MPA design.

Selection of sites for MPA networks should follow a well-laid plan that is guided by local and national priorities, expresses clear goals and objectives, and lists focused, practical criteria to guide site selection. In actuality, MPA selection is frequently determined by opportunity (a strong show of public and/or government support) or crisis (a high level of threat to a site that is considered important for any reason), which is how tourism and fisheries often lead the process. Opportunities and crises are likely to arise at intervals, but one needs to get ahead of them if MPA selection is to proceed in a planned and orderly fashion. In this context, it is important that we move fast to secure adequate levels of protection for coral areas that are both resistant and resilient to mass bleaching, perhaps one of the greatest emerging threats of this century faced by coral reefs.

Initiatives for establishing MPAs can come from local governments or communities. Sites protected in this way have high local significance, but often may contribute relatively little to the national conservation objectives, have little scientific basis, and could succumb to a mass bleaching event. Nonetheless, because they enjoy strong local support and require little personnel, time, and money to manage, they should be viewed as potentially useful contributions to conservation. They should be endorsed, but not counted as substitutes for larger more valuable MPAs that really do contribute significantly to conservation and have good survival prospects. Having now recognized the undisputed value of local community support for MPAs, we will need to find non-scientific, understandable, and compelling means to communicate the need for strict protection of coral areas that are resistant and resilient to bleaching.

The criteria and approach for selection of coral reef MPAs have evolved relatively little from their original sources (IUCN 1981; Salm & Clark 1984; Kelleher & Kenchington 1992; Salm & Price 1995; Nilsson 1998; Salm *et al*. 2000). However, here we propose additional principles and criteria for coral reef MPAs under an entirely new category: ***survivability***.

Additional Principles for the Selection of Coral Reef Marine Protected Areas

First principle: *the survival prospects of coral reef communities in the face of large scale climate related events, such as their resistance and resilience to bleaching, should receive serious consideration in the selection and design of MPAs.*

Unless MPAs are designed and managed specifically to survive massive climate-related bleaching and mortality, coral reef communities in even the most effectively managed sites may be susceptible to such events. Thus we need to identify coral reef communities with a high probability of resistance and resilience to such unmanageable events as mass bleaching, afford them high levels of protection, and incorporate these into larger management areas that include as diverse an array of reef types and habitats.

Second principle: *replication of MPAs along prevailing, larvae-carrying currents (corridors of connectivity) will greatly increase the probability of survival for multiple reef communities and their prospects for reciprocal replenishment.*

Threats to coral reefs are unprecedented in their severity and extent, and it is not altogether predictable where and when global events will strike. Replication of MPAs and connectivity among them will help some reef communities to escape major impact, aid in the recovery of damaged areas down-current, and increase the prospects for reef survival at current levels of biodiversity. Thus replication of sites and connectivity among reefs (as expressed through larval dispersal along currents and through species movements) should also be applied to the selection of sites.

Third principle: *MPAs should be selected to represent the full national or regional range of coral reefs, and should include other functionally linked habitats such as seabed, seagrass, mangrove, and coastal and riparian areas.*

Patterns of climate-related bleaching and mortality are neither fully understood nor predictable. But it is known that pockets of resistance to bleaching are distributed among reef types and different parts of the same reefs. It is also known that the reef ecosystem extends beyond the physical reef framework to include a range of habitats that are linked by physical and ecological processes, including the transport of nutrients by currents or daily feeding migrations of reef species. These processes help to maintain coral reef communities in a "healthy" state. Thus protection of a range of different reef communities and linked habitats will increase the prospects that some will survive bleaching. Furthermore, maintenance of unimpeded reef processes will enhance the prospects of rapid recovery in areas that suffer different levels of mortality.

The Coral Reef Marine Protected Areas Site Selection Process

The objective relating to the first selection principle above is: *to identify and adequately protect reefs or parts of reefs that reliably have one or more environmental factors present that:*

- *have a significant positive effect on coral reef resistance and resilience to climate related bleaching and enhance recovery of affected areas; and*
- *are sufficiently reliable and persistent through time in their presence and effect.*

These sites should be the essential foundation for a network of coral reef MPAs that is designed to conserve representative biodiversity.

The objective relating to the second selection principle above is: *to identify and adequately protect reefs and reef complexes that are linked by prevailing currents, larval dispersal where this can be demonstrated, and species migrations*.

These sites should be the essential building blocks of a network of coral reef MPAs.

The objective relating to the third selection principle above is: *to identify and adequately protect reefs of different morphology, species composition, and environmental conditions along with the adjacent habitats that are linked through physical or ecological processes*.

These areas and their surrounds should be listed as candidate sites for establishment as MPAs.

The resistant coral communities should be considered for zoning as strict reserves under the highest levels of protection. The resilient coral communities and adjacent linked habitats should be zoned as strict reserves under high levels of management to enable control of all direct and upstream sources of threat.

The four basic steps followed in systematic selection of MPAs (Salm *et al.* 2000) can be easily adapted to apply specifically to coral reefs. These steps include the collection, analysis and synthesis of data leading to the identification of candidate sites, followed by the application of criteria to select specific sites for protection.

1. Data Collection

A simple low cost option is to follow the following procedure:

1. Identify areas with high cover of old corals: at the simplest level, and in the absence of any other information, undertake field surveys to identify those places where corals survived an earlier known bleaching event. Having survived one major bleaching event, these sites are more likely to survive a future one and should be listed as candidate sites. Presence of high cover of old corals could also indicate areas where coral communities are at low risk of exposure to bleaching because of their location and prevailing climate and oceanographic conditions. These should also be considered candidate sites.
2. In the absence of any capacity, time or resources to undertake a formal oceanographic analysis, refer to existing atlases or texts that could supply information on SSTs, current strengths, presence of upwelling sites, exposure of corals at low tides, and coral communities in or near estuaries, bays and lagoons with predictably turbid waters. Oceanographers, dive operators, researchers and fisheries colleagues may be able to assist.
3. Consult atlases, nautical almanacs, oceanographic texts, and oceanographers to produce maps in greatest possible detail of local inshore as well as offshore currents and combine these with data on fish movements obtained from fisheries authorities and reports.
4. Supplementary data will need to be collated from the literature, field surveys, interviews, and any other sources to help identify other values (e.g., endangered species habitat, fish spawning aggregations and nurseries, suitability for tourism, and so on depending on identified local or national priorities), levels and types of use, types and severity of threats, relevant oceanographic data, administrative districts, and locations of existing or proposed MPAs.

2. Data Analysis

Once the list of candidate reef sites are identified based on their probability of surviving a mass bleaching event, overlay the most detailed possible maps of current speeds and directions and fish movements to identify likely connectivity.

When the supplementary data collection is complete, the information is analyzed to show areas with concentrations of resources, human activities, and threats to resources, or any other required information, such as areas of conflicts among activities and other interests, or sites of specific interest (e.g., fish spawning aggregations). Areas with concentrations of resources are all obvious candidates for conservation. However, the specific objectives of the MPA network planning process may call for strict protection of specific sites with high value for only one interest, such as the breeding site of an endangered animal.

The simplest way to achieve these analyses is by map overlay. First, a base map is prepared to an appropriate scale. Individual coral reefs, differentiated by those with and without the necessary factors that provide resilience to bleaching, current patterns, and other data elements (turtle beaches, seabird islands, spawning aggregations, fishery activities, and so on) are then mapped onto transparent overlays of this base. Next, the transparencies are overlaid to show the areas with resource concentrations. These, together with any sites with specific interests can then be identified as higher level candidates for selection. Overlay analysis can be done most efficiently using GIS applications, where accessible.

3. Data Synthesis

Maps (graded if possible into high, medium, low levels) of activities, threats to reef communities, or conflicts between biodiversity conservation and developments can be combined with the composite map resulting from the preceding analysis to refine the MPA identification process. This synthesis helps to impose a measure of priority for protection on the candidate sites. For example, the level of use, dependence or threat by people on a reef community with high resistance or resilience to bleaching could be used to indicate priority among candidate sites to safeguard coral biodiversity. Similarly, the vulnerability to bleaching and/or probable connectivity as revealed by analysis of current speed and direction may be used to determine the choice between two candidate reef sites with different probable responses to a mass bleaching event.

Another application of data synthesis is to develop an understanding of spatial relationships among biological factors (e.g., species), ecological processes (e.g., nutrient transport), and human activities. Overlays of ocean currents, nutrient sources (such as estuaries), and resource distributions can be combined to show the specific support systems for species or ecosystems - all of which are candidates for protection. Also, by combining overlays of human activities, and particularly proposed developments, a picture can be synthesized of potential conflicts between reef conservation and development objectives and activities, and of priority areas for action.

It can be very revealing to compare the candidate sites resulting from data synthesis with the range of established or proposed MPAs. As well as indicating the needs for additional MPAs, this comparison may show that some sites hold low priority because of their susceptibility to bleaching.

The identification procedure outlined in the data analysis and synthesis steps above will provide a long list of candidate sites for protection. Selection of the specific sites for protection from this list will require the application of a carefully compiled sample of relevant criteria.

4. Application of MPA Selection Criteria

The process and value of applying criteria to site selection has evolved little over the past two and a half decades, and it doesn’t go far enough. The devastating impact of the 1998 El Niño bleaching and the predictions of increased severity and frequency of these events, coupled with unprecedented fishery and other pressures on coral reefs, leave little doubt that the world will need to go further if we expect reefs to survive. We will need to select areas for protection we know have a high probability of surviving a mass bleaching event. Furthermore, we will need to acknowledge the greatly diminished relevance of urgency, opportunity, and political or popular pressure, which in the past have often made the first areas for protection so obvious that there has been no need or opportunity to apply criteria at any stage.

For the purposes of biodiversity conservation, criteria that favor survival are of critical importance. Criteria stressing naturalness, uniqueness, and habitat or species diversity are complementary, as they lead to the selection of sites with maintenance of biodiversity, safeguarding of ecological processes, and species replenishment as the primary management objectives.

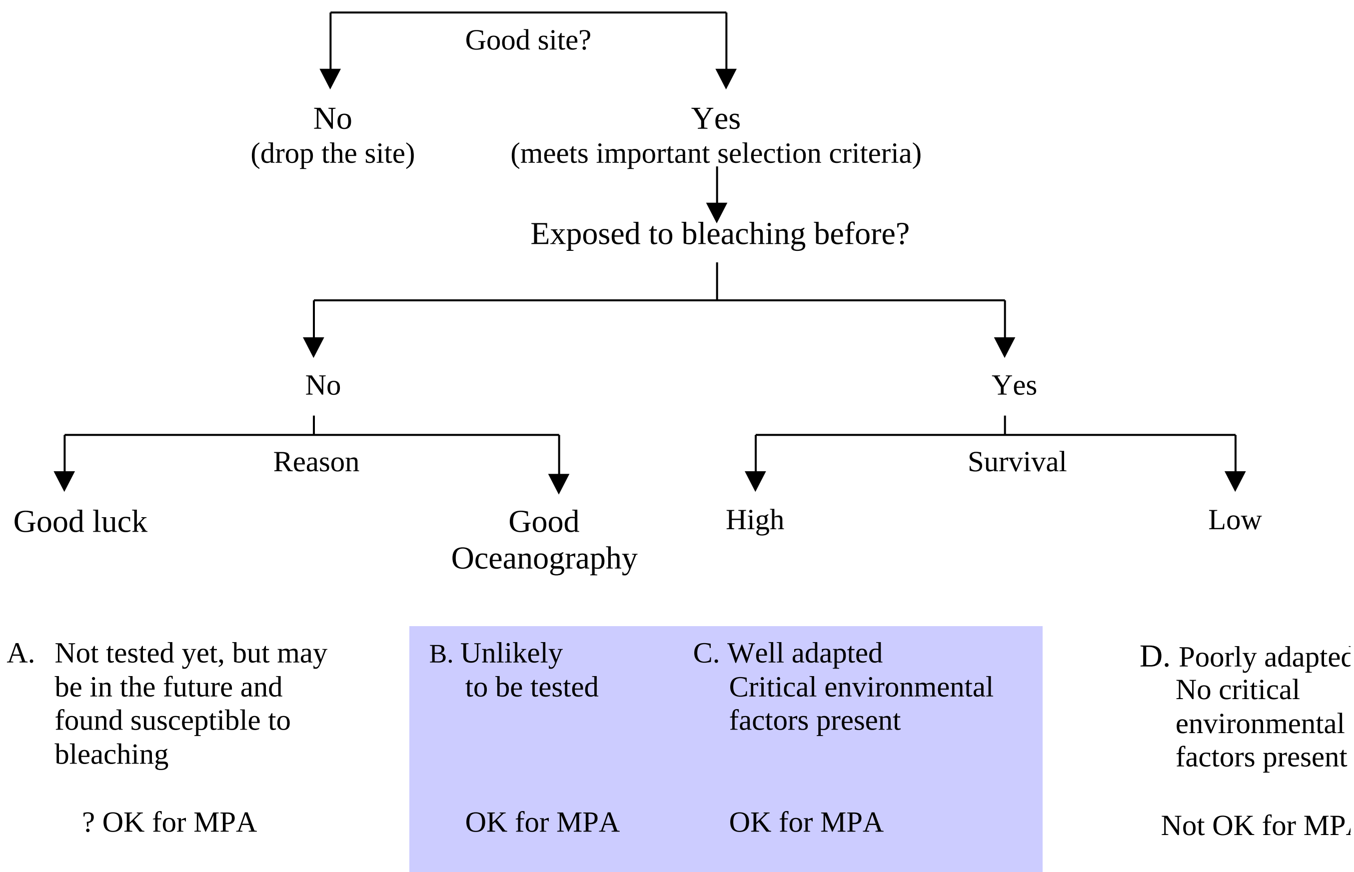
Criteria have two functions. They initially serve to assess the eligibility of sites for protected area status. Their principle role, however, is to order eligible sites according to priority in the selection process. The final determinants of how many sites are selected for protection have been influenced by such factors as national policy, the urgency for action, the availability of financial and manpower resources, and, in the case of some developing countries, the extent of international concern and assistance. Faced as we are with unprecedented rates of reef destruction caused by the direct actions of people and such large scale, unmanageable phenomena as mass bleaching, urgency for action has never been greater; national policies need to reflect this, and we can no longer afford the costs of inaction.

There really is no substitute for the thoughtful application of criteria for MPA site selection. The careful identification and application of selection criteria help to clarify the goals of MPA networks and their component sites. This process helps too to ensure representation of all interests and priorities in the MPA network. Ultimately, a network MPAs should aim to include the full range of coral reef types and biodiversity, be interconnected by larvae-carrying currents, and include other functionally linked habitats, whether contiguous or geographically separated.

It is possible to apply the following assumption as a shortcut to identify MPA sites that have a high probability of surviving bleaching events (Figure 1): corals that have survived a previous known bleaching event have a high probability of surviving a future one. These sites can be identified by the presence of living coral colonies covering a range of sizes, including large old ones.

The decision tree in Figure 1 will greatly facilitate narrowing down the options for new MPA sites. It starts from the presumption that criteria for MPA selection have been agreed and applied to select candidate sites with high biodiversity value. Based on their response when tested by elevated SSTs, these candidate sites are then appraised for their survivability in the context of global warming.

Figure 1. Decision tree to aid selection of candidate MPA sites



(modified from Done, 2001)

Criteria for the Selection of Coral Reef Marine Protected Areas

In this section, we list the proposed new survivability criteria for coral reef MPAs. Existing criteria are summarized in box 1 below, but are not described in detail in this report.

EXAMPLES OF MPA SELECTION CRITERIA

Social Criteria:
Social acceptance, public health, recreation, culture, aesthetics, conflicts of interest, safety, accessibility, research and education, public awareness, conflict and compatibility, benchmark

Economic Criteria:
Importance to species, importance to fisheries, nature of threats, economic benefits, tourism

Ecological Criteria:
Biodiversity, naturalness, dependency, representativeness, uniqueness, integrity, productivity, vulnerability, spawning aggregations

Regional Criteria:
Regional significance, subregional significance

Pragmatic criteria (these are weighted heavily):
Urgency, size, degree of threat, effectiveness, opportunism, availability, restorability, enforceability

Source: Salm *et al.* (2000)

Survivability Criteria. Long term survival prospects of coral reef communities in the face of ENSO-linked bleaching can be enhanced by the presence of any of the following environmental factors acting together or in isolation.

1. Resistance to coral bleaching as manifested by the reliable presence of one or more of the following factors that are not shut down by ENSO events:
   Factors that promote water mixing
   - Proximity to deep water and regular exchange with cooler oceanic water
   - Localized upwelling of cool water
   - Permanent strong currents (tidal, ocean, eddies, gyres)

   Factors that screen corals from damaging radiation
   - Deep shade from high land profile
   - Shading of some coral assemblages by complex reef structure, multilayered coral communities, or steep slopes
   - Orientation relative to the sun (north facing slopes in northern hemisphere, south facing in southern hemisphere)
   - Presence of consistently turbid water

Factors that indicate potential pre-adaptation to temperature and other stresses

- Frequent exposure of corals at low tides
- Highly variable seawater temperature regime (pond effect in shallow back-reef lagoons)
- History of corals surviving climate related bleaching events
  - High diversity and abundance of coral reef species
  - Wide range of coral colony size and diversity in different reef zones, including centuries old colonies
  - High live coral cover

Factors that favor survival of at least some coral communities

- Stable salinity regime
- Large area with wide depth range and habitat variability
- Low risk of exposure to climate related temperature stress at the location (high latitude)

2. Resilience to coral bleaching as manifested by the reliable presence of one or more of the following environmental factors that may promote recovery:

Factors that indicate strong recovery potential

- Strong coral recruitment
  - Presence and abundance of coral recruits
  - Recruitment success

Factors that increase coral larval transport to the site

- Strategic location that will maximize both strong and reliable recruitment of all species present, whether from other reefs or from within the same reef complex
- Direct current links with neighboring reefs and the strong likelihood that a proportion of the propagules will effectively seed other areas
- Replication of sites along prevailing currents to insure against the risk of no meaningful recovery after a large scale event eliminates essentially all corals and/or other taxa.

Factors that prepare the substrate for successful coral larval recruitment

- Diversity and abundance of different coral reef taxa, especially high herbivore densities, and representative community structure.
- Low abundance of coralivores, bioeroders and disease.
- Good potential for recovery because effective management regime in place.

DESIGN PRINCIPLES FOR CORAL REEF MARINE PROTECTED AREAS

This section is intended to help coral reef MPA planners and managers to select reef components for protection and draw protected area boundaries.

Resistance to bleaching (coral colonies don’t bleach or bleach but don’t die) may vary among different parts of a reef. Reef communities with high resistance to bleaching should be afforded highest levels of protection and should be buffered within larger management areas. These resistant communities play a critical role in reef survival by providing the larvae to recruit to and enable recovery of affected areas. See Salm *et al*. (2001) and West (2001a, b) for additional detail on the concept of resistance and its application to MPA design.

Resilience to bleaching (coral colonies bleach and partially or entirely die but the coral community recovers rapidly to its former state) also varies among different parts of a reef and among different reefs in the same complex. Reefs or their components that demonstrate resilience to bleaching need to be included in zones of high levels of protection and should be managed to maintain conditions that facilitate successful coral recruitment and recovery. These resilient areas may support different and complementary elements of biodiversity and will likely play important roles in conservation.

Connectivity within reefs is an important determinant of MPA zone and boundary locations. Strict protection zones that include areas of high resistance to bleaching should be positioned upcurrent of sites with lower resistance to facilitate their recovery by larval recruitment.

Connectivity among reefs is an important determinant of MPA network design. A network of MPAs linked by prevailing currents to each other will facilitate the recovery of damaged areas and the maintenance of biodiversity through larval exchange.

The reef ecosystem extends beyond its physical boundary to include the neighboring habitats with which it interacts, especially seagrass beds and back-reef lagoons, which provide important fish nurseries. All these linked habitats need to be considered and managed as parts of a single functional unit.

Coral reefs are linked intimately by dynamic processes (currents, rivers, and species movements) to distant areas and may be influenced by the activities there. These activities require some form of control if reef communities in a protected area are to survive.

At a *critical minimum reef size*, the diversity of coral, and presumably of other reef taxa, begins to decrease (Salm 1984). The core area of a protected coral reef, including its component resistant and resilient communities, should be as large as possible to preserve high diversity of reef biota.

Replication of protected resistant and resilient coral communities at multiple sites increases the probability that some will survive bleaching to help the recovery of affected areas. MPAs should be designed to include multiple samples of protected resistant and resilient coral reef communities.

Coral reef users, like traditional fishers, dive operators, and other user groups, should be assisted to understand the principles of coral resistance and resilience to bleaching and should participate early in coral reef MPA selection and design. This will help to ensure clear understanding of the concept of reef survivability, strong grassroots support for conservation at the site, and effective partnership in management where appropriate.

MANAGEMENT GUIDELINES FOR CORAL REEF PROTECTED AREAS

This section is intended to assist coral reef MPA managers develop and implement a series of management actions that focus on enhancing coral reef survivability in the face of climate-related coral bleaching and mortality. As there will be much overlap between management of reefs for survival from bleaching and from other factors, the following actions are intended to supplement, not replace, the usual suite of coral reef management activities that managers would implement in MPAs.

It is more usual for management actions in MPAs to be defined by a site conservation planning approach that leads through problem identification to threat abatement: specific (usually immediately obvious) impacts on the conservation targets are identified and management actions identified to resolve these at the MPA site. The focus of such an approach on coral reefs generally would be to identify areas of dead or damaged reef or depleted species, determine the causes of the damage or depletion and their sources, and design a course of action to address these sources of impact. For example, coral breakage might be the consequence of anchors (the cause) associated with the tourism industry (the source). The remedial management measures might call for placement of moorings, reef closures to facilitate recovery, and a range of regulations and awareness materials to support these actions.

In another example, reduced grouper populations may be the result of fishing of spawning aggregations (the cause) to supply the live reef food fish industry (the source). This could require protection measures at the spawning aggregation sites linked to local and national level government regulations and international codes of conduct and tracking to monitor the trade. These are admittedly simplified examples, but are included to make the point that management in both cases is linked directly to site-based threat abatement, which is our usual practice.

Site conservation planning is well designed for localized threat abatement and may even help to anticipate some potential stresses linked to distant sources (like sedimentation from a proposed development linked to deforestation in a watershed, as one example). However, “site” conservation planning is linked through its title and its intent to a “site:” targets at the site, stresses at the site, sources linked to those stresses at the site, and *management* strategies for their control or abatement. Global, largely unmanageable stresses do not fit easily into this approach and are better addressed through strategies for *mitigation*.

We can go about this mitigation process by doing what we should always do for MPA management planning in coral reef areas through the threat abatement process, but would add an extra dimension – planning for survivability in the face of emerging threats. We would start by identifying areas with resistance to bleaching and would give these high levels of protection along with the more usual range of critical habitats like spawning aggregations, nesting islands (for seabirds), beaches (for turtles), nurseries (for fishes), and so on. Also, to enhance the recovery of areas affected by bleaching, we should position resistant sites upcurrent of both resilient areas and others that succumb to bleaching and die. By reducing or eliminating threats in areas prone to bleaching, we can provide conditions favoring larval recruitment and recovery of coral communities.

In addition, we need to establish ecologically sound boundaries for MPAs and their included zones. To determine these boundaries, we need to answer two basic questions (Salm *et al*. 2000):

1) Which habitats should be included in the MPA and its component zones of different uses and management focus?
2) How large should the MPA and each of its zones be?

Which Habitats?

To help preserve the full range of coral reef biodiversity, a MPA should contain many different reef zones and habitats for a steady and varied supply of larvae to replenish naturally damaged areas and to replace dead or emigrated organisms. These habitats should span a broad range of depths, exposures to prevailing winds and currents, and distances from shore. This is particularly important to ensure that some coral communities survive bleaching and provide a source of larvae to settle and help reestablish portions of the reefs that die off.

In practice, three categories of habitats should be considered for inclusion in coral reef MPAs: coral habitats, contiguous habitats (i.e., submerged, intertidal, or above water), and distant linked habitats. Although the latter two categories may not be physically part of the reef community, they are incontrovertibly linked through function.

Coral Habitats
Different reef types, depths and zones within reefs are characterized by different coral assemblages and different responses to temperature stress and bleaching. There are corals in shallow lagoons, reef flats and reef crests, and others that are found down the reef slope, some of which only occur deeper than about 20 meters. Dominant corals and coral diversity differ in each assemblage; for example, sheltered reefs may have dense overlapping colonies of staghorn coral (*Acropora*) or large whorls of leafy corals (*Montipora*, *Pachyseris*, *Echinopora*) that are aesthetically pleasing, but have few species. Such reefs may be valuable for tourism, but are less so for conserving a representative range of biodiversity. They also tend to bleach readily and die.

Different coral reef communities result from distinct processes (e.g., seaward reefs endure greater wave stress than lagoon reefs), as is reflected in variations in coral assemblages and zonation patterns. Some reef habitats are relatively unchanging, while others are constantly interrupted by wave stress or natural periodic exposure to air or freshwater. These habitats contribute different types and quantities of larvae to the reef system and may exhibit different susceptibility to bleaching. It is important to identify the reef types and, as far as possible, the various coral communities, and to include multiple examples of each in the protected area where possible.

Contiguous Habitats
Examples of the following habitats may often be included incidentally in MPAs, but, if reefs are to flourish, they should be deliberately identified and protected within MPA boundaries.

Reef flats. Corals on reef flats and upper reef crests that are exposed at low tides often exhibit high levels of resistance to bleaching and will be important providers of larvae that may settle in dead areas and aid their recovery. Also, these reef flats often provide vital nurseries for reef fishes that will move onto the reef and help reestablish communities affected by bleaching. Nitrogen and organic material produced on the reef flats or transported from there in the form of feces of herbivorous fishes and other organisms all contribute valuable nutrients to the reef community and aid in its functioning and recovery.

Back-reef lagoons. Coral assemblages in back-reef lagoons, especially shallow lagoons behind fringing reefs, are routinely exposed to wide temperature fluctuations (pond effect) and consequently may exhibit some acclimatization to temperature stress and resistance to bleaching. They are also important nurseries for fishes. Corals in naturally turbid deeper lagoons also show higher resistance to bleaching than their conspecifics in clear waters over barrier reefs.

Seagrass beds and sand flats. Seagrass beds and sand flats surrounding coral reefs are important feeding grounds for nocturnal feeding fishes, such as snappers and grunts, which shelter on reefs by day. When they return to the reef, these fishes deposit nutrients in the form of feces that are introduced to the reef food web and contribute to the growth and recovery of reef communities.

Mangroves. The generally turbid waters and shading effect of mangroves may also reduce the susceptibility of corals there to bleaching. Mangroves also provide nurseries for juveniles of certain reef fishes (e.g., butterflyfishes, parrotfishes, and snappers). Where they are close enough to reefs, mangroves provide feeding grounds to fishes that shelter on the reefs. They also introduce fixed nitrogen and organic detritus into the trophic system of reefs, as do reef flats and seagrass beds.

Beaches and dunes. Coastlines are dynamic zones. Disturbances to them may cause beach erosion and alteration of the natural cycle of accretion and erosion of sand along the shore, increase turbidity of inshore waters, or even smother living reefs with excessive sediment. This is especially true of sand cays which have been known to move across reefs, fall off into deeper water and disappear for good as at Maziwi Island, Tanzania. Before its disappearance, Maziwi Island was the most important green sea turtle nesting beach off mainland Tanzania.

Linked Habitats
Sources of stress to coral communities that are not clearly discernible may be difficult to control, such as deforestation and development in a watershed. While watersheds are not obvious or easy candidates to include in coral reef MPAs, they may be connected to reefs by streams and coastal currents and damaging activities there will need to be controlled by a reefs to ridges approach to MPA planning or complementary coastal zone management approaches.

An interesting speculation: Sorokin (1973) has suggested that dissolved organic compounds originating in the Antarctic are transported through deep ocean currents and are brought to the surface to enhance productivity on West Indian coral reefs. But of course a management plan for Antigua would not extend to Antarctica. The fact still illustrates the far-reaching consequences of distant events in the ocean realm and emphasizes the need to manage reefs as one of many integral parts of reasonably larger ecosystems, rather than as autonomous units.

How Large?

In theory, we know that we could help prevent loss of species within an MPA if we maintained a balance between the rate of species loss and the immigration rate of replacement species. It is this balance, or whole-reef equilibrium, that maintains the status quo of general reef species composition. If the balance is tipped in favor of extinction by damage and death of corals on the target and up-current source reefs, the protected area will lose species. There are many natural stresses such as tropical storms, from which reefs recover naturally with time. Human activities increase the burden of stress and may prevent normal recovery by increasing the extinction rate or decreasing the immigration rate. Coral bleaching has increased the stakes – it challenges us to take immediate action based on our best information, and to refine our management focus as the science and experience develop. Following the lead from fisheries, we need to err on the side of precaution and create larger more viable MPAs to safeguard our global coral reef biodiversity and resources.

To maintain the balance between immigration and extinction rates we need to ensure a steady source of recruits (eggs, larvae, and juveniles) to replenish stressed areas. Large reefs may be self-replenishing. They manage to achieve this because their large size allows portions of reefs damaged by bleaching, slumping (collapse of the reef slope), storm surges, freshwater flooding, crown-of-thorns starfish, or other stresses, to be replenished by recruits from undamaged parts of the same reef. Such large reefs are mosaics of patches in different stages of community recovery and development.

On balance, fewer large coral reef MPAs are to be favored over a greater number of smaller ones. However, there could be distinct advantages of having a number of small, strictly protected areas established to protect pockets of high resistance and resilience to bleaching (and other valuable assets, such as fish spawning aggregation sites), if these are embedded in a larger management area.

The optimal size of a coral reef MPA is designed around a strictly protected zone or core or collection of these, each of which encompasses sufficient target coral area to be self-replenishing for all species. This focus on replenishment is particularly important if preserving biological diversity is the principal management objective, but may seem less important for other objectives - for example, maintaining the area's value for recreation, tourism, research, education, and spawning of specific fishes. However, coral bleaching has shown us that replenishment is an equally important consideration for reef survival, irrespective of the management objective. Bleaching shows no regard for MPA zones, boundaries, regulations, or management efforts, unless these are designed to meet the survivability requirements.

Determining the critical minimum size of coral reef communities for these to be self-replenishing is still very imprecise science. However, if urgency or lack of funds and suitable personnel prevent studies from beginning immediately, a core area of about 450 ha should be designated, if possible, until the estimate can be verified by studies (Salm 1984, Salm *et al*. 2000). Also, the core should be selected so that it encompasses as diverse as possible a range of reef habitats. A single reef is preferable, but a cluster of small reefs will probably be equally effective when these are managed as an integrated unit.

The design team should choose carefully from the many objectives for protecting coral reefs - providing for recreational activities, contributing to fisheries, preserving biological diversity, or protecting endangered species or the breeding stock of other valuable species. But primary importance should be given to survivability and the subsidiary objectives worked into this. Objectives are the basis of design, so take care to define and obtain wide consensus on these and to include survivability among them.

Management Actions

In addition to the above two very basic, generic elements of design, managers can take some specific actions to help strengthen the resilience of the coral communities in MPAs by helping to (a) ensure the survival of bleaching resistant coral communities, and (b) enhance recovery of bleaching susceptible ones.

The following recommended actions contain some direct management interventions that may be controversial in some cases because they require manipulation of natural systems. Managers should use their own judgement in deciding what they can and cannot do as guided by their organizational policies.

Protecting Bleaching Resistant Communities

1. Survey MPAs and their adjacent areas for the presence of environmental factors that cause bleaching resistance and identify coral communities protected by them (see *Survivability Criteria* on p.9).
2. For resistant coral communities *inside* established MPAs, consider securing high levels of protection for them by revision of zone boundaries or establishment of special zones to encompass these sites.
3. For resistant coral communities *outside* established MPAs, consider extending MPA boundaries to incorporate these sites if feasible or the creation of new MPAs to include them.

Tracking Bleaching

1. Revise monitoring programs or design new ones to enable recording of the response to bleaching events of as great as possible a selection of different coral communities.
2. Track the bleaching widely throughout the MPA to identify areas that either do not bleach or do bleach, but suffer minimal mortality – these are the resistant sites that should be strictly protected.

Preventing Damage

1. Prohibit all forms of extractive use (other than specific management related removal of damaging species) in the protected, bleaching resistant sites.
2. Control visitor access to protected, bleaching resistant sites through either total exclusion or carefully controlled access.
3. For carefully controlled access to bleaching resistant sites in MPAs:
   - prohibit anchoring, install moorings, and require boats to attach to these;
   - in channels through reefs and along walls, consider permitting drift diving as a means to avoid contact with corals;
   - control numbers of visitors and link access to payment of premium access fees to help compensate for the higher management cost of these areas;
   - require accreditation of operators before issuing them special licenses to access resistant sites;
   - implement regular monitoring for visitor damage and close down access for two-year recovery period if damage is detected.
4. For bleaching susceptible sites, consider closure or exclusion of certain potentially damaging activities after a bleaching event to enable rapid recovery.

Enhancing Recovery

1. Conduct regular surveys for coral predators such as predatory molluscs (e.g., *Drupella*) and echinoderms (e.g., *Acanthaster*) and remove these on sight from the strictly protected bleaching resistant zones and adjacent, managed, susceptible areas.
2. Implement regular surveys of sea urchins, such as *Diadema*, which can occur in large infestations and inhibit growth of coral recruits.
3. Control harvest of herbivorous fishes in recovery sites to enable them to graze down algae that overgrow and exclude coral recruits from establishing themselves.

REFERENCES

Done, T. 2001. Scientific Principles for Establishing MPAs to Alleviate Coral Bleaching and Promote Recovery. Pp. XX-XX *in* R.V. Salm and S.L. Coles (eds). *Op cit*.

Goreau, T.J., T. McClanahan, R.Hayes, and A.E. Strong. 2000. Conservation of Coral Reefs after the 1998 global bleaching event. *Conservation Biology*, 14: 5-15.

IUCN. 1981. *Principles, Criteria and Guidelines for the Selection, Establishment and Management of Mediterranean Marine and Coastal Protected Areas*. (UNEP/IG.20/3). Gland, Switzerland.

Kelleher, G. and R. Kenchington. 1992. *Guidelines for establishing marine protected areas.* A Marine Conservation and Development Report. IUCN, Gland, Switzerland.

Nilsson, P. 1998. *Criteria for the selection of marine protected areas _ an analysis*. Swedish Environmental Protection Agency, Stockholm, Sweden: 54 pp.

Salm, R.V. 1984. Ecological boundaries for coral reef reserves: Principles and guidelines. *Environ. Conserv.* 11(1): 7-13.

Salm R.V. and J.R. Clark. 1984. *Marine and Coastal Protected Areas: A Guide for Planners and Managers*. IUCN, Gland, Switzerland: 302 pp.

Salm R.V., J.R. Clark and E. Siirila. 2000. *Marine and Coastal Protected Areas: A Guide for Planners and Managers*. IUCN. Washington DC, USA: 371 pp.

Salm, R.V. and S.L. Coles (eds). 2001. *Coral Bleaching and Marine Protected Areas*. Proceedings of the Workshop on Mitigating Coral Bleaching Impact Through MPA Design, Bishop Museum, Honolulu, Hawaii, 29-31 May 2001. Asia Pacific Coastal Marine Program Report # 0102, The Nature Conservancy, Honolulu, Hawaii, U.S.A: 118 pp. (document available from: www.conserveonline.org)

Salm, R. & A. Price. 1995. Selection of Marine Protected Areas. Pp. 15-31 in Gubbay, S. (ed.). *Marine Protected Areas: Principles and Techniques for Management*. Chapman & Hall, London: 232 pp.

Salm, R.V., S.E. Smith and G. Llewellyn. 2001. Mitigating the impact of coral bleaching through marine protected area design. Pp. 81-88 in Schuttenberg, H.Z. (ed.). *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."* Coastal Management Report #2230, Coastal Resources Center, University of Rhode Island: 102 pp.

Sorokin, Y.I. 1973. Microbial aspects of the productivity of coral reefs. Pp. 17-45 in O.A. Jones and R. Endean (eds). *Biology and Geology of Coral Reefs, vol.2, Biology I.* Academic Press, New York, San Francisco, London: 480 pp.

West, J.M. 2001a. Environmental Factors that Correlate with Coral Bleaching Resistance and Resilience. Pp. XX-XX *in* R.V. Salm and S.L. Coles (eds). *Op cit*.

West, J.M. 2001b. Environmental Determinants of Resistance to Coral Bleaching: Implications for Management of Marine Protected Areas. Pp. XX-XX *in* R.V. Salm and S.L. Coles (eds). *Op. cit*.

Westmacott, S., K. Teleki, S. Wells, and J. West. 2000. *Management of bleached and severely damaged coral reefs*. IUCN, Gland, Switzerland: 36 pp.

Wilkinson, C. (ed.). 1998. *Status of Coral Reefs of the World: 1998*. Australian Institute of Marine Science, Queensland, Australia: 184 pp.

Wilkinson, C. (ed.). 2000. *Status of Coral Reefs of the World: 2000*. Australian Institute of Marine Science, Queensland, Australia: 363 pp.