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A global protocol for monitoring of coral bleaching

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Abstract

Coral bleaching and subsequent mortality represent a major threat to the future health and productivity of coral reefs. However a lack of reliable data on occurrence, severity and other characteristics of bleaching events hampers research on the causes and consequences of this important phenomenon. This article describes a global protocol for monitoring coral bleaching events, which addresses this problem and can be used by people with different levels of expertise and resources.

Introduction

Coral bleaching is considered to be one of the most significant and widespread threats to coral reefs. When predicted temperature increases due to global warming over the next 100 years are compared to the known temperature bleaching limits of corals, the depressing conclusion is that, by 2020, coral reefs in many parts of the world may suffer bleaching and mortality every year. Unless corals are able to adapt to rising temperatures, reefs may suffer progressive deterioration and species loss, resulting in major ecological impacts and consequent social and economic impacts on the human communities in many countries that depend on reefs for their livelihoods. Global warming and greenhouse gas emissions represent a relatively new and severe threat to the sustainability and productivity of coral reefs, and the services they provide to humans.

Accurate and precise estimates of the severity, timing and spatial patterns of coral bleaching and their subsequent mortality are essential if we are to gauge the level and immediacy of the threat and to develop appropriate management actions to alleviate the ecological and social impacts. Unfortunately, lack of standardized protocols has led to a proliferation of survey methods, surveyed variables and varying definitions for coral bleaching in different regions. Most reports are anecdotal and many are provided by people with limited training in quantitative ecological assessments. This makes comparison between areas exceedingly difficult. In addition, there is considerable variability in the effectiveness of the various monitoring procedures that have been used. Consequently, some surveys have not made effective use of personnel and time while others have collected data of limited use due to problems in observational bias and lack of standardization between observers.

There is an urgent need to obtain better information on bleaching events around the world. This information is crucial to a scientific understanding of the fate of coral reefs and to the feasibility and practicality of developing management strategies to increase the resistance and resilience of reefs to bleaching and associated mortality events. The World Wide Fund for Nature (WWF), the WorldFish Center and the Great Barrier Reef Marine Park Authority have recently developed a protocol for monitoring coral bleaching and for managing the resulting data. This protocol aims to provide a simple yet consistent set of procedures to document the extent and severity of bleaching events, and to collect information on other issues such as the causes and impacts of these events. This paper summarizes the key components of the protocol and is intended to raise awareness of its existence as well as promote its use in all regions.

Who will use the Protocol?

It is assumed that this guide will be used by people wishing to record the basic features of a bleaching event and to document overall impacts and possible causal relationships. The two primary aims are, firstly, to document global patterns and, secondly, to understand smaller-scale patterns and variations that may have local management implications. This protocol is designed to produce more quantitative data on the global distribution, severity, and frequency of bleaching events so that a more rigorous analysis of the relationship between coral reef status and climate change/global warming can be carried out.

The protocol will serve as:

- a quick guide on what to do if bleaching is observed;
- a guide on how to use time and resources most effectively to observe and record bleaching;
- an introductory resource on what bleaching is and how to recognize it;
- an aid in making immediate reports on coral bleaching when seen in the field;

- a guide for the development of structured and detailed assessments of bleaching as well as its causes and consequences.

Quick Guide

This section should be used if you want some quick guidance on what to do if you have seen (or think you have seen) coral bleaching. In addition to providing an introduction on how to distinguish bleaching from other phenomena which cause coral to go white, this section takes you through the steps needed to decide what type of measurements and monitoring activities would be most appropriate for the circumstances you have observed.

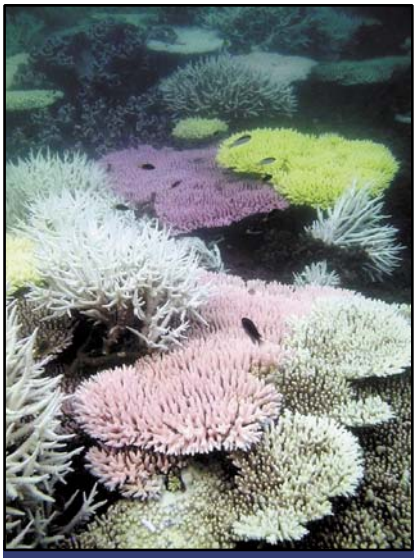
Box 1 below sets out the basics steps that should be followed if you observe coral bleaching.

How do I identify coral bleaching?

Coral bleaching occurs when corals lose the single celled algae (zooxanthellae) that live within their tissues. These golden brown coloured algae occur in varying densities in reef corals (and other reef invertebrates) and give them a light tan to deep chocolate brown colour. Where additional pigments exist within the animal cells, this brown colour can be overlaid by different hues, such as blue, green, purple or yellow (Fig. 1). When corals lose their zooxanthellae, the white skeleton can be seen through the transparent animal tissue, making the corals look bleached white. In cases where the corals possess additional animal pigments, bleached corals take on vivid fluorescent hues, with no trace of the normal brown background colour.

Corals which have bleached are not initially dead. On close inspection it may be possible to see the transparent polyps and tentacles of bleached colonies. However corals cannot remain bleached indefinitely. If the stress is not too severe or prolonged, they can slowly regain or regrow their zooxanthellae and survive. But in severe bleaching events many corals subsequently die, causing major changes in the structure and function of the reef ecosystem, with a possible cascading impact on other organisms.

Recently-dead corals are also white and can sometimes be confused with bleached corals. Bleached corals can be distinguished from dead corals by a careful examination of the coral surface. Completely bleached corals look extremely clean and almost glow when seen underwater. If the surface is sediment free and if you can see minute transparent tentacles when you view the colony from the side, the coral is



Ray Berkelmans/ReefBase

Fig. 1. In some corals, loss of their zooxanthellae reveals underlying colors in the animal tissue (pink, yellow, blue, green, orange) that can be very vivid. These corals are still considered bleached.

Box 1. What do I do if I see bleaching?

1. Record your observation and fill out a NOAA/ReefBase Questionnaire (www.reefbase.org/input/bleachingreport/index.asp) and contact local experts (if any).
2. If bleaching is widespread or severe, send out a message on coral-list to advise others.
3. If you cannot fill out most of the basic information in the questionnaire, consider returning to the site as soon as possible for a reconnaissance visit to get additional general information. Ask around and get other people who regularly visit the reef to indicate if they have seen bleaching and where. Get them to fill out a ReefBase/NOAA Questionnaire – or make a note of these observations yourself and send them to ReefBase.
4. Ask yourself why you are interested in this event. If you are not interested in formally answering the above questions (or any others you can think of) then continue to record the basic information on the Questionnaire and send it to ReefBase.
5. If you want to formally answer questions similar to those in step 4, then you will need to design a monitoring program (see below).
6. If you decide to implement a monitoring program, choose the methods and sampling protocol that best suits the questions you wish to answer, and the resources you have available to you; or pick a scenario that comes closest to your situation and either follow the protocol suggested or modify it to suit your situation.
7. Take photographs to illustrate conditions that you see and any unusual features. If using a digital camera, try to use one with a resolution of at least 3 megapixels.
8. Store your data in a safe place and then share it with others by publishing it yourself or sending the summary data to ReefBase.

not dead. Dead or dying colonies are unable to actively remove the sediment that rains down in all but the clearest reef environments. So any accumulation of even small amounts of sediment is a sign of mortality. Algae rapidly colonise dead coral surfaces, so a thin film or haze of green, brown or yellow is also a sure sign that the coral is dead rather than bleached. In the case of some fleshy corals, you can detect the presence of live tissue by gently touching the coral surface.

Bear in mind that bleached corals may ultimately die and dead colonies may be a final stage in the bleaching process. If your first observation is of large numbers of recently dead corals, you may have to look for other evidence to determine if this has been caused by bleaching. Other common causes of recently dead corals are crown-of-thorns starfish (COTS), disease and freshwater flooding.

Designing a program for your needs

In this protocol we use three resource scenarios (Box 2) to illustrate the activities that might be possible under different resource constraints.

Before undertaking the detailed procedures for making the recommended measurements, it is important to take time to consider what questions you wish to address, what measurements are most appropriate and where and how often they should be taken. While a set protocol in which everyone records the same measurements might seem to be the best approach, this is not likely to work in practice. The unique circumstances and sets of questions faced by different organizations and teams will require different monitoring programs. In many cases people have specific methods or procedures that they prefer because of their skill or experience. These can still provide data that are comparable across programs. Thus, the most effective approach is to carefully identify the objectives of the monitoring initiative and to then design a program that draws from a list of commonly used and comparable procedures, to best suit the locally specific questions, environment, resources and logistics.

The design of a monitoring and assessment program for coral bleaching should be approached in the same way as any monitoring program. A logical top-down approach should be used, beginning with the identification of the specific objectives (often phrased in the form of a question) and area under consideration (global, national, a reef, a dive spot). This should be followed by the selection of: variables to be measured; methods of measurement; sampling site; and sampling frequency. Fieldwork should commence only after all these factors have been specified. This is especially important when a substantial investment in time and resources is to be made in monitoring a bleaching event or events. Careful thought about objectives and spatial scales will also result in more relevant and reliable information being gathered even when assessment is limited to casual observations and questionnaires.

In theory, an unlimited number of questions could be posed in relation to coral bleaching. The more specific the question, the more specific the design of the monitoring program. This will result in data that can be used to answer the questions unambiguously. A monitoring program can be designed to address more than one question, but there is a risk that if questions are not specific enough the result will be a monitoring program that may not answer any of the questions.

Picking a monitoring program to suit your situation

It is not possible to fully specify all monitoring activities that should be carried out under every possible situation. Table 1 provides a guide to the type and frequency of monitoring that should be considered for different resource scenarios, and for two typical questions. Further guidance on other questions can be found in the full protocol. It is important to invest time in designing the monitoring to suit your specific situation and to use the points in Table 1 as a guide only.

Box 2. Resource scenarios.

Resources, in terms of funding, staffing and expertise, are an important constraints on the capacity of an organization or team to respond to a coral bleaching event. Recognizing these constraints and working within them to maximize the quality and relevance of data is essential to a successful monitoring program. Three generalized resource scenarios are described below as a guide in selecting a set of monitoring tools that are most suitable to the circumstances.

Low Resources	Moderate Resources	High Resources
• No dedicated funds • No or limited numbers trained staff • Active volunteers available (with diving qualifications) • Concern over plight of local reefs	• Some levels of dedicated funding available for bleaching work • Formal bleaching monitoring program exists or will be established • Trained staff available (or funding exists to train new staff) • Moderate level of logistic support (boats, computers, labs, scientifically qualified staff, good communications)	• Substantial funding available • Dedicated bleaching monitoring program exists • Highly qualified scientific team • High level logistic support • Strong community and government commitment to program

Table 1. Monitoring activities for various scenarios.

Question	Resource scenarios		
	1. Low	2. Medium	3. High
A. What is the general extent and severity of the current bleaching event?	**A1** • Record variables from questionnaire when visiting any sites (affected and non-affected) • Circulate questionnaires amongst local divers and other reef users • Submit information to ReefBase	**A2** • Carry out tasks in A1, plus synoptic surveys of representative sections throughout the area you are interested in (timed swims or manta tow) • Identify major species affected (take photos or specimens)	**A3** • Carry out tasks in scenario A1 and A2, plus conduct detailed surveys of representative sites using transects and some precise measure of percentage of coral affected (line transect, photo-transect) • Use aerial surveys (if water clarity and tides permit) or dedicated ship time to obtain synoptic estimates over wider geographic area
D. What are the ecological impacts on the reef system?	**D1** • Carry out tasks in A1 • Conduct before (if possible) and after bleaching observations including mortality/recovery • General estimates of coral cover over time	**D2** • Carry out tasks in A1, A2 and D1 • Monitor tagged corals – track mortality/recovery through visual estimates • Collect measured estimates of benthic cover through time (transects/quadrats)	**D3** • Carry out tasks in A1, A2, D1 and D2 • Monitor tagged corals and quadrats – measure mortality and recovery using video or photographic records • Collect measured estimates of benthic cover through time at higher taxonomic resolution (transects/quadrats) • Survey transects for other macro-invertebrates • Conduct surveys of fish abundance and diversity

A - Severity and Extent of Bleaching
D - Ecological Impacts

Outline of a typical monitoring plan

The following example outlines how one might develop a program to address questions A and D with moderate resource levels.

Prior to any bleaching being observed

If you are concerned about a particular area even before any bleaching has occurred, it is important to carry out some surveys before bleaching occurs to allow for specific before and after comparisons to be able to gauge ecological impacts.

- If visibility and local conditions permit, carry out manta tows of the whole area of interest to determine the distribution of habitats and the general characteristics of each habitat and zone.
- Choose replicate sites that are representative of the area (if more than one habitat or reef zone is being investigated, choose replicate sites in each of these). Sites can be selected using the results of the manta tow, local charts or aerial photographs.
- Using timed swims (15 minutes around an area of about 50m x 20m) or manta tows (5 x 2 minute tows), estimate hard coral cover (HCC), bleaching, and any other major indicators of coral stress.
- If further detailed information is needed, carry out replicate Line Intercept Transect (LIT) surveys at each site to measure percentage cover of principal benthos.
- If accurate data on the percentage of bleached corals which die or survive are needed, tag at least 20 corals at each site and record species, bleaching and mortality (presumably none at this stage).
- Regularly check the NOAA CHAMP website (http://orbit-net.nesdis.noaa.gov/orad/coral_bleaching_index.html) or the ReefBase hotspot/bleaching maps for hotspot reports during the high temperature season to anticipate bleaching events.

After onset of bleaching is observed (during peak of bleaching)

- Fill out the ReefBase questionnaire and distribute it to other divers or scientists in the area to do the same.
- Carry out extensive manta tow and/or timed swims to determine the extent/severity/variability of bleaching.
- Determine if existing sites adequately represent the areas bleached. If not,

add additional sites to cover a range of levels of bleaching intensity.
- Carry out belt transects (or LIT if the bleaching is very frequent) to get accurate estimates of the percentage of corals bleached at different levels of intensity.
- Record condition of all tagged corals. If there is not a reasonable number of bleached corals at each site (at least 10) then additional bleached corals should be tagged and their condition recorded.

Further monitoring during and after bleaching

- Repeat synoptic surveys (manta tow or timed swims) at regular intervals. Suggested optimal regime would be at 2 months, 6 months, 12 months and 24 months after initial bleaching. Full post-bleaching LIT surveys should be repeated once bleaching is no longer present and all corals have either died or recovered. If resources permit, further recovery LIT surveys should be conducted annually or every two years.

Key Variables to Monitor

The most important variable to monitor in all bleaching surveys is the percentage of the total living coral cover that is bleached. While line transects, photographic transects and other detailed survey methods yield this data from direct measurements, broad-scale surveys such as timed swims and manta tows, and questionnaires, generally provide only subjective estimates that are often grouped into categories. In order to be able to compare surveys from different locations and times, we recommend a standard set of bleaching categories for all such surveys (Table 2).

Table 2. Standard bleaching categories for use in broad-scale assessments.

Index	%*	Description	Visual Assessment
0	< 1	No bleaching	No bleaching observed, or only very occasional, scattered bleached colonies (one or two per dive)
1	1-10	Low or mild bleaching	Bleached colonies seen occasionally and are conspicuous, but vast majority of colonies not bleached
2	10-50	Moderate bleaching	Bleached colonies frequent but less than half of all colonies
3	50-90	High bleaching	Bleaching very frequent and conspicuous, most corals bleached
4	>90	Extreme bleaching	Bleaching dominates the landscape, unbleached colonies not common. The whole reef looks white

* Estimated % of total coral cover bleached

Standardization is also important in estimating the percentage of other coral reef benthic organisms. We recommend that the categories established by the Australian Institute of Marine Science and the Global Coral Reef Monitoring Network (GCRMN) be followed. The full protocol sets out the details for several other key variables that should be monitored in bleaching studies.

As part of the protocol, a series of data sheets has been created to assist in recording standard information in a consistent format. In addition, a Microsoft Access database with data entry forms designed to resemble the data sheets has been constructed. Both data sheets and a blank copy of the database can be downloaded from ReefBase at www.reefbase.org/bleachingdatabase.

Conclusions

In this summary paper, we highlight the objectives and many of the key components of the coral bleaching protocol. In the protocol we have assembled a virtual toolbox of methods and measurement tools which will, hopefully, cover a wide range of scenarios while at the same time promoting the collection of more standardized data. If the protocol is successful in this, we should be able to carry out much more meaningful analyses of the global and regional patterns of coral bleaching over the next decade and test the various predictions that have been made regarding the fate of coral reefs in the face of continuing global warming.

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