Module 3: Assessing the ecological impacts of mass coral bleaching and identifying resilient areas

Aims

In the previous section, you learned how to predict the risk of a mass bleaching event using a range of available tools and information services. This module deals with the first part of the response strategy that managers should take when a mass bleaching event occurs. When mass bleaching occurs, managers must rapidly assess the extent and severity of bleaching in order to make timely and effective management decisions and communicate the situation to communities, stakeholders, managers, government departments and the media. This module aims to provide managers with the skills and knowledge necessary to assess the impacts of bleaching on coral communities and ecosystem processes. Certain reef areas may escape bleaching or may recover rapidly from bleaching due to underlying physical characteristics of the local reef environment or physiological attributes of the coral community present. The occurrence of a mass bleaching event provides managers with an opportunity to identify resilient reef areas, gain an understanding of the underlying causes of resilience and incorporate these factors into management planning. This module also aims to provide managers with the ability to identify resilient reef areas and incorporate resilience monitoring into bleaching assessment protocols.

Module Outline

Learning objectives

By the end of this module you will have:

- ✓ An understanding of the why we need to assess the ecological impacts of mass coral bleaching.
- ✓ The ability to identify bleached corals.
- ✓ The ability to assess the geographic extent and severity of a mass bleaching event.

- ✓ An understanding of how bleaching assessments differ to normal monitoring.
- ✓ In-water experience carrying out a bleaching impact assessment.
- ✓ The ability to link bleaching observations with in-situ temperature measurements to calculate bleaching thresholds.
- ✓ A knowledge of reef characteristics that may promote resilience to bleaching.
- ✓ Identify characteristics of a healthy reef from a local perspective
- ✓ The ability to use bleaching events to identify resilient reef areas.

Background

When a mass bleaching event occurs, reef users, other stakeholders, the media, and senior government officials will want to know: '*How bad is it? What are the impacts to the reef?*' and '*What will it mean for the local stakeholder community?*'. Managers must rapidly assess the extent and severity of mass bleaching in order to make timely and effective management decisions and communicate the situation to others. This module details a range of methods that can be used by managers, scientists and community members to identify bleaching and assess the extent and severity of a mass bleaching event. Since mass bleaching is transitory in nature, the decision about when to conduct a rapid assessment of bleaching impacts, including which protocol can be best mobilized and used, may have significant implications for the survey results and for any conclusions made from those results. Experience from around the world during previous bleaching events has led to the development of standard set of strategies that can help with monitoring-related decisions. The World Wildlife Fund (WWF), the WorldFish Centre, and the Great Barrier Reef Marine Park Authority (GBRMPA) have compiled these experiences into *A Global Protocol for Assessment and Monitoring of Coral Bleaching (can be downloaded from the ReefBase website:* www.reefbase.org). The *Protocol* aims to provide detailed guidance for planning and implementing bleaching assessments under a range of resource settings, while ensuring that data are useful and readily integrated into a global database of coral bleaching impacts. The Response to Climate Change Workshop held in Hawaii seeks to build upon these established techniques, and incorporate the knowledge of our communities' traditional systems. This suite of techniques from different perspectives will allow managers to gather sufficient information to report to concerned community members, stakeholders, managers, decision makers, media and the general public.

Ongoing monitoring is also required to document the long-term ecological impacts of mass bleaching and other major disturbances on reef ecosystems. It is necessary to track changes in reef communities over longer timeframes (several years to decades) in order to estimate the probability and rate of recovery, increase the ability to determine the cause of changes in reef condition, and evaluate the effectiveness of management strategies. Knowledge shared between cultural practitioners and management can provide insights into the on-the ground effectiveness of management practices in valuable ways that would be otherwise very difficult to come by. Maintenance of long-term monitoring programs and relationships between managers and the communities they serve will assist managers in detecting gradual changes in coral community structure that may occur due to bleaching and mortality and to maximize their ability to attribute chronic impacts to particular stresses, including coral bleaching. Monitoring on an annual or semi-annual basis should be complemented with additional surveys timed to detect the occurrence and impact of coral bleaching at long-term monitoring sites. The data from such targeted surveys will help managers determine the relative influence of coral bleaching on the long-term dynamics of coral reef ecosystems. Coral reef monitoring protocols have been developed for a wide range of skill levels, ranging from *Reef Check* for volunteers, to the comprehensive *Survey Manual for Tropical Marine Resources* developed by the Australian Institute of Marine Science (AIMS) and the Global Coral Reef Monitoring Network for reef scientists and managers. This section highlights the relative benefits and weaknesses of a range of assessment approaches, and introduces the value of incorporation of traditional Hawaiian knowledge so that managers can make the best choice of methods to be included in a bleaching response plan.

The severity of bleaching responses varies between reefs during mass bleaching events. Identification of areas that have historically had high resilience to bleaching provides the basis for a network of refuges to underpin resilience-based management of the reef ecosystem. Refuges serve as a seed bank to facilitate the recovery of areas with lower natural resilience, and will play a central role in networks of protected areas designed to maximize ecosystem resilience. The identification of resilient areas as an ecosystem management strategy is already being applied in various locations around the world. The experiences gained from these initiatives will help to refine knowledge and develop additional protocols for the identification of resilient areas. The outcomes of these early tests of resilience management strategies will also provide important information about the extent to which the factors that confer resilience on an area will remain consistent over time. As managers, you too can contribute to this knowledge through incorporating resilience monitoring into bleaching monitoring protocols.

The Nature Conservancy, together with a group of partners, has developed a Reef Resilience (R^2) Toolkit to help managers develop and apply resilience principles for managing coral reefs. This module, as well as Module 7 of the workshop, draw from R^2 to review the features that resilient reefs, and to outline how to identify areas of high resilience on reefs and incorporate these into management plans and strategies. Managers are directed to the R^2 toolkit or website (www.reefresilience.org/index.htm) for a more detailed discussion of how to identify resilient areas and incorporate these areas into MPA design.

Reference materials

Journal Articles and Books

Oliver, J, P. Marshall, N. Setiasih and L. Hansen 2004 *A Global Protocol for Assessment and Monitoring of Coral Bleaching*. WorldFish Center, Penang, Malaysia and WWF Indonesia, Jakarta. 35 pp.

Siebeck, U. E., Marshall, N. J., Klüter, A. and Hoegh-Guldberg O., 2006 *Monitoring coral bleaching using a colour reference card.* Coral Reefs 25: 453-460.

Etc……

Web Links and Organisations

Bleaching assessment protocols:

Great Barrier Reef Marine Park Authority Coral Bleaching Response Plan:
http://www.gbrmpa.gov.au/__data/assets/pdf_file/0020/13169/Coral_Bleaching_Response_Plan_2006-07_Final.pdf

Reef Check Bleaching Monitoring Protocol:
http://www.reefcheck.org/protocols_data/Monitoring_Instruction.php

Australian Institute of Marine Science – coral bleaching index:
http://www.aims.gov.au/pages/search/search-coral-bleaching.html

BLAGRRA: Atlantic and Gulf Rapid Reef Assessment Bleaching Protocol:
http://www.agrra.org/BLAGRRA/index.htm

TNC Florida Reef Resilience Program, Expert Response Protocols
http://www.nature.org/wherewework/northamerica/states/florida/preserves/art17499.html

Information and databases:
ReefBase global database on bleaching threats:
http://www.reefbase.org/global_database/default.aspx?section=t4

Section 3.1.1 Assessing Ecological Impacts of Bleaching

Module 3

Assessing the Ecological Impacts of Mass Bleaching and Identifying Resilient Areas

Section 3.1 Assessing Ecological Impacts

Outline:

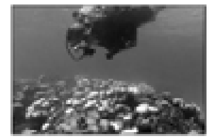
3.1.1 Identifying bleached corals

3.1.2 Estimating the extent and severity of mass bleaching

3.1.3 How warm is too warm?
- Identifying bleaching thresholds
- Linking observations with *in situ* temperature

3.1.4 Techniques for bleaching assessment



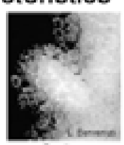


3.1.1 Identifying bleached corals

Bleached coral: distinguishing characteristics

Current bleaching :
- Coral tissue still present/alive
- Pale, fluorescent or completely white appearance
- Areas of pale/white tissue across exposed parts of whole colony (rather than starting from tips or base)
- Numerous colonies over large reef area

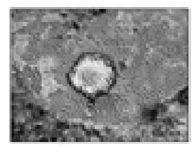
Previous bleaching : harder to distinguish
- May be due to other factors (salinity, freshwater etc.)


Porites


P. meandrina

Distinguishing bleaching from other issues


Growth Tips


Disease


Crown-of-thorns

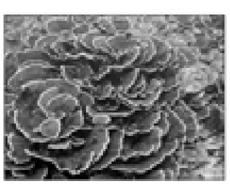

Fish Bites


Other Predation


Barnacle infestation

Distinguishing bleaching from other issues

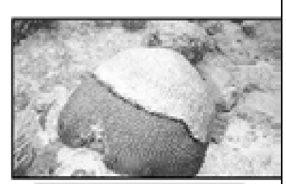
Confusing bleaching with Growth tips and margins




Distinguishing bleaching from other issues

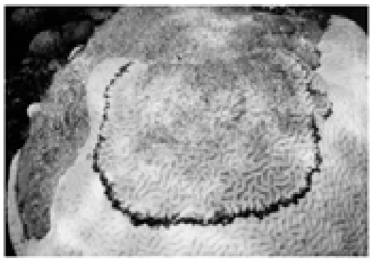
White and Black Band Disease

- Black Band Disease
  - black mat (a few mm to cm) wide
  - moving across the surface of the skeleton
  - leaving behind bare white skeleton
- White Syndrome
  - Pacific host genera: *Acropora, Montipora*
  - Patchy, irregular shapes
  - several mm per day




Distinguishing bleaching from other issues

What's going on here?



Bleaching + recent death from black-band disease

Distinguishing bleaching from other issues

Parrotfish Bites

- Tissue loss and skeletal scarring in patches or strips

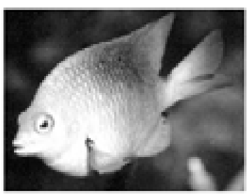
Montipora sp.

stoplight parrotfish (*Sparisoma viride*) biting *Montastraea annularis*

Distinguishing bleaching from other issues

Damselfish Bites

- Look for small, circular (<1cm diameter) lesions in the coral



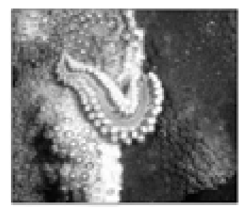
Stegastes planifrons (threespot damselfish)

damselfish bites in *Montastraea*

Distinguishing bleaching from other issues

Predation by Fireworms (***Hermodice carunculata*, Caribbean**)
(***Eurythoa complanata*, Hawaii**)

H. carunculata on *M.faveolata*

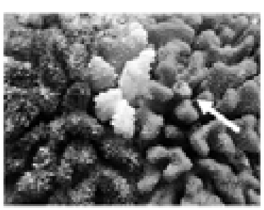


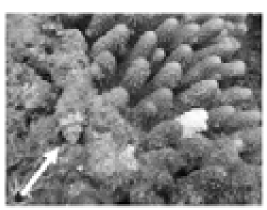
H. carunculata on *M. faveolata* with white plague

Distinguishing bleaching from other issues

Predation by gastropod molluscs

- Look for snail(s) close to white skeleton

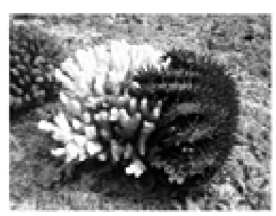


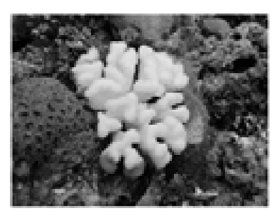


Distinguishing bleaching from other issues

Predation by crown-of-thorns seastar (*Acanthaster planci*)

- Tissue has been consumed, leaving bare white skeleton
- Look for other signs of similar predation and/or prey in the area

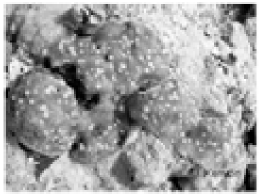


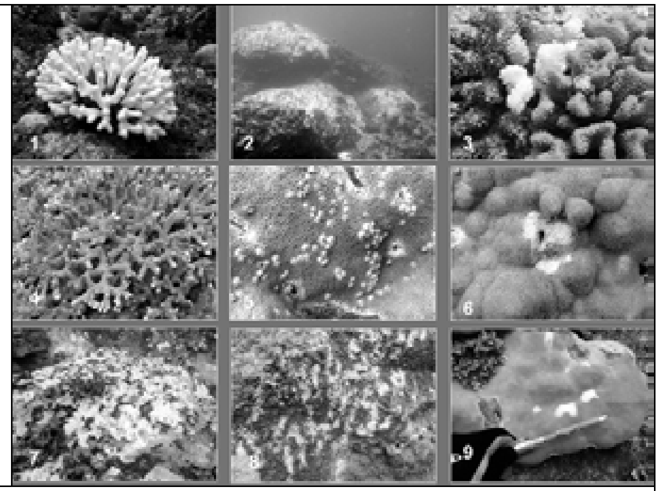


Distinguishing bleaching from other issues

Barnacle infestations

- Multiple focal white spots
- Closer inspection: individual coral calices invaded by barnacle





Distinguishing bleaching from other issues

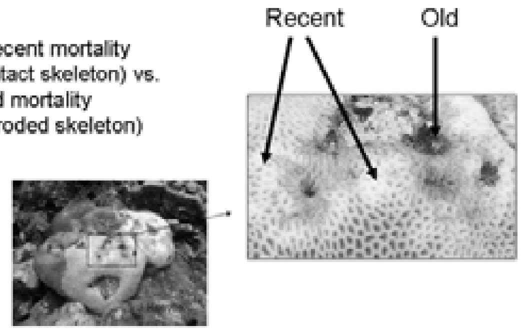
Recent Bleaching vs. Old, Undetermined Mortality

"Recently dead" is defined as any non-living parts of the coral in which the corallite structures are either white and still intact or slightly eroded but identifiable to species.

"Old dead" is defined as any non-living parts of the coral in which the corallite structures are either gone or covered over by organisms that are not easily removed (certain algae/invertebrates).

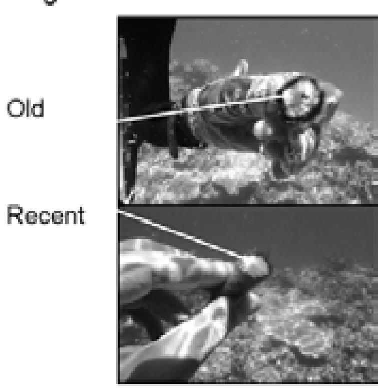
Distinguishing bleaching from other issues

Recent mortality (intact skeleton) vs. old mortality (eroded skeleton)



Distinguishing bleaching from other issues

Recent versus old mortality



Identifying bleached corals: Challenges

Pitfalls

- Natural growth at tips
- Confusing normally pale corals
- Patchy bleaching
- Predation
- Disease
- Commensalism
- Recognising recovery

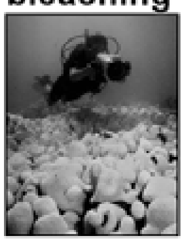
Main messages

- Know your local corals
- Bleaching is dynamic & prolonged
- Bleaching is variable

Section 3.1.2 Bleaching Extent and Severity

Section 3.1.2 Bleaching Extent and Severity

Estimating the spatial extent and severity of bleaching

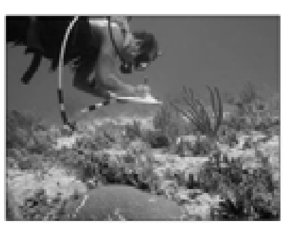

Why do we need to measure bleaching?

1. To make timely and effective management decisions
2. To communicate / educate
3. Answer questions from stakeholders, media, government, concerned public:

'How bad is it?'
What are the impacts to the reef?
What will it mean for the local stakeholder community?

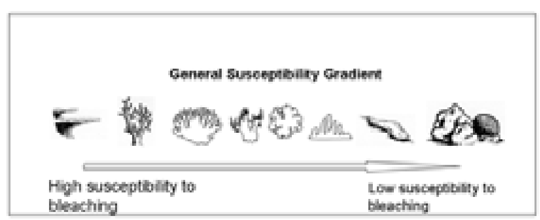
Bleaching is variable

- Bleaching varies at all scales:
  - regions, reefs, sites, species, colonies
- Numerous sources of variation:
  - Exposure, including depth & habitat
  - Environmental history
    - acclimatization
    - shift towards resistant species



NEED TO ASSESS THE EXTENT AND SEVERITY OF THE BLEACHING EVENT

Corals show differential susceptibilities



Species vary in susceptibility

Broad pattern of resistance

Taxonomic patterns are diagnostic

Recognizing the severity/stage of bleaching

Low

Bleaching severity

High

- Pale (discoloration of coral tissue)
- Partially Bleached (Patches of fully bleached or white tissue)
- Bleached (tissue is totally translucent, no zooxanthellae pigmentation visible)

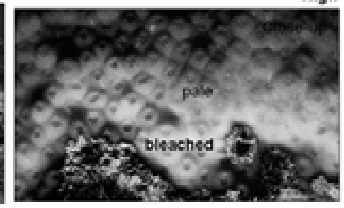
Within Colony Variability in Severity

Low

High

Pale or yellowish

- Polyps that have either just started to bleach (or are recovering from bleaching).



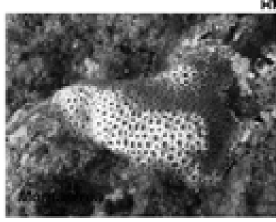
Within Colony Variability in Severity

Low

High

Partial bleaching

- Patches of fully bleached, translucent tissue



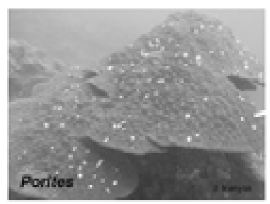
Within Colony Variability in Severity

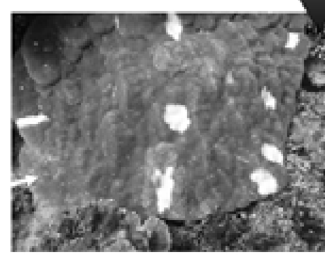
Low

High

Partial bleaching

- Blotchiness (multi-focal)
  - Mostly massives





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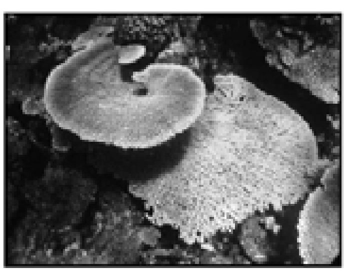
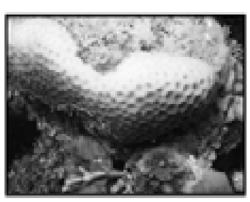
Within Colony Variability in Severity

Partial bleaching

- Exposed upper surfaces (role of shading)





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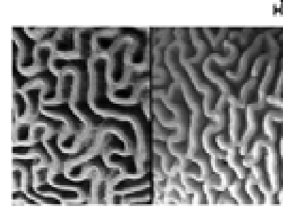
Within Colony Variability in Severity

Low

High

Fully Bleached

- Tissue is totally translucent, no zooxanthellae pigment visible



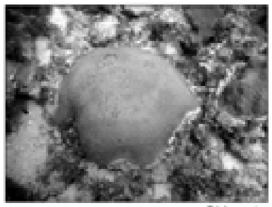
Healthy vs. Bleached

Within Colony Variability in Severity

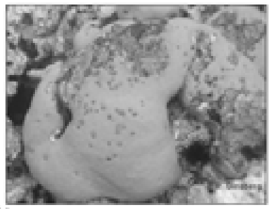
Pastel and totally bleached

- Some bleached corals glow pale purple, pink or blue!
- Non-zooxanthellae pigments confer color

Partially Bleached

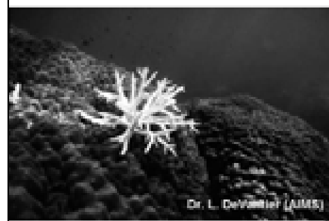


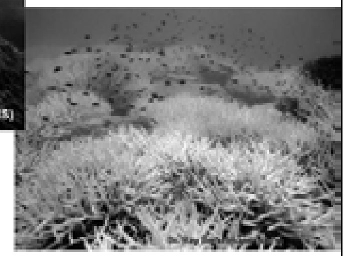
Fully Bleached



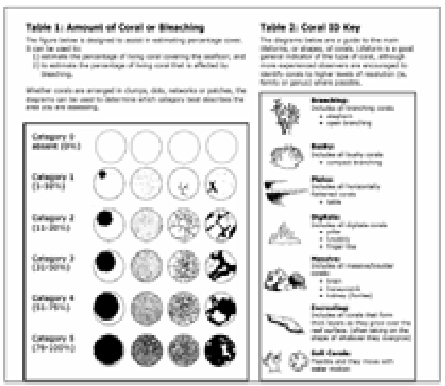
Siderastrea siderea

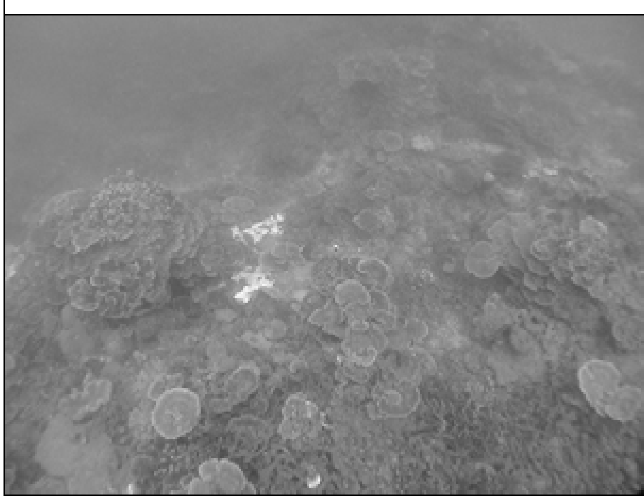
Estimating the spatial extent of bleaching

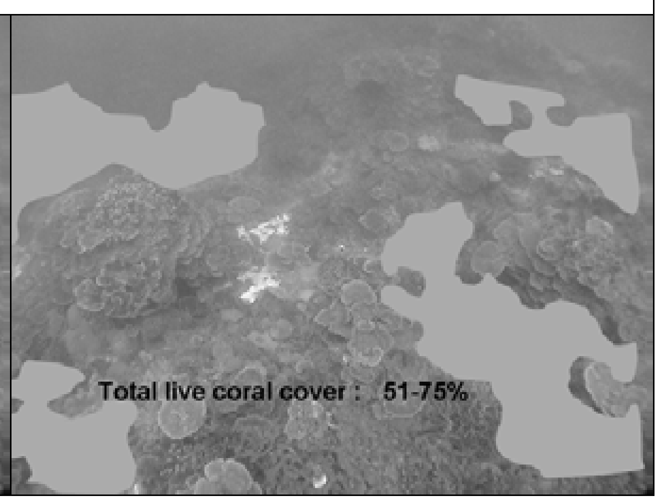


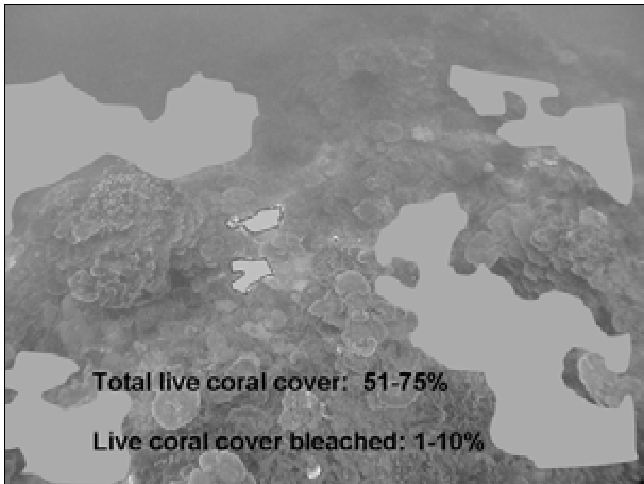


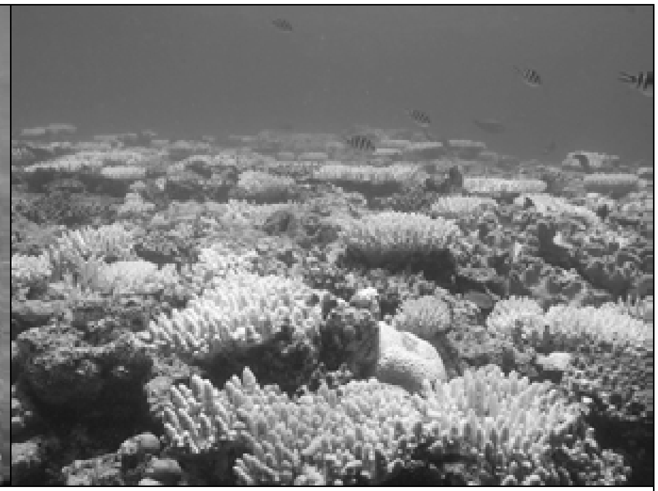
Estimating % coral cover and % bleaching

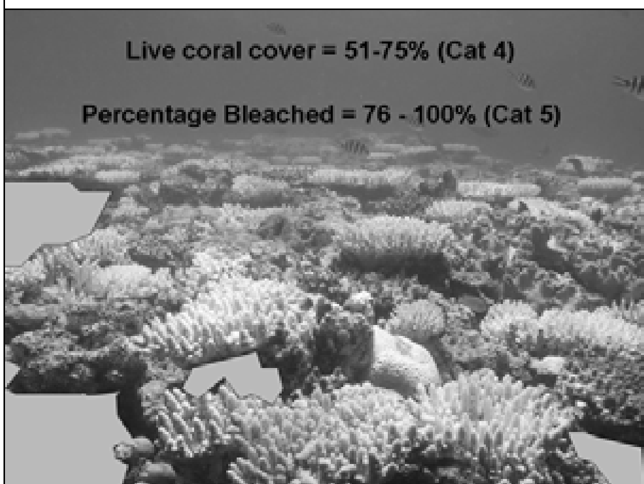


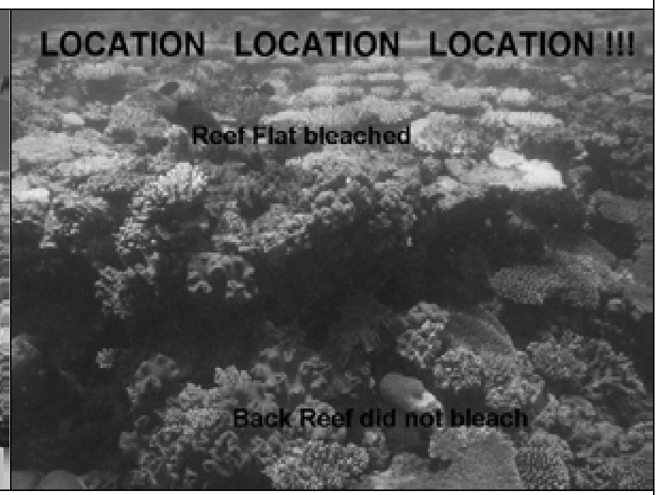





Total live coral cover: 51-75%
Live coral cover bleached: 1-10%




Live coral cover = 51-75% (Cat 4)
Percentage Bleached = 76 - 100% (Cat 5)


LOCATION LOCATION LOCATION !!!
Reef Flat bleached
Back Reef did not bleach


Species susceptibility is important !!


76 – 100% (Cat 5 Bleaching)
Mass bleaching is very hard to miss!

Section 3.1.3 Indentifying Bleaching Thresholds

Module 3

Assessing the Ecological Impacts of Mass Bleaching and Identifying Resilient Areas

Section 3.1.3 Identifying bleaching thresholds

Why do we need to know bleaching thresholds for corals?

- To be able to predict bleaching events related to warm water anomalies
- To understand how climate change is likely to affect coral communities
- To examine whether corals are adapting to climate change

Section 3.1.3 Outline:

How warm is too warm?

- Intensity of warm water event
- Duration of warm water event
- (modified by irradiance, water motion and other factors)

2) Determining bleaching thresholds:

- Based on experimental data
- Based on average maximum temperatures
- Based on past bleaching events

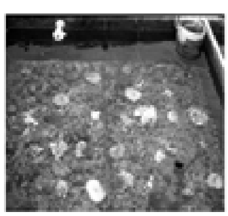
Controlled laboratory experimentation:

Mesocosm Facility, HIMB

Thermal Pollution Experimental Facility 1969

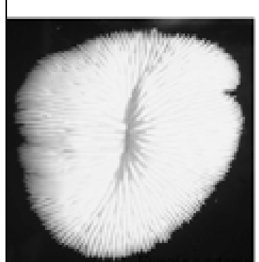
Heat Pump, circulating pumps and controls.

Titanium heat exchanger system. All wetted surfaces of inert material.



Bleached corals 1970

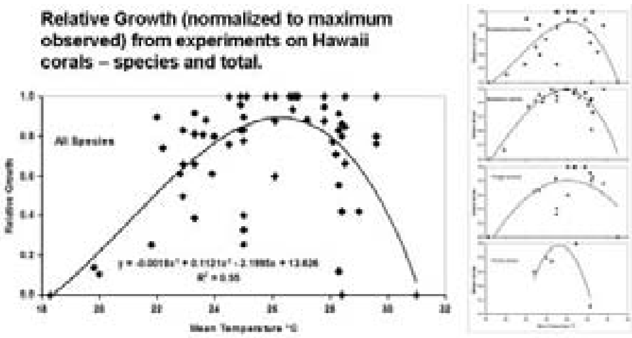
Experimental determination of growth, bleaching, and mortality.



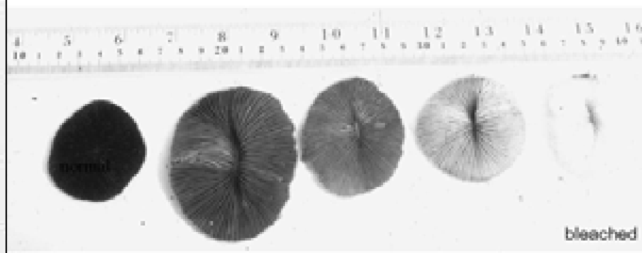
Bleached corals from mesocosm experiments, 1970

Experimental determination of growth, bleaching, and mortality.

Relative Growth (normalized to maximum observed) from experiments on Hawaii corals – species and total.

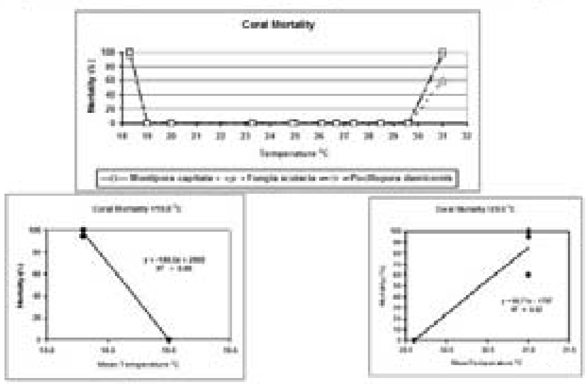


Recovery of Experimentally Bleached corals, 1970.

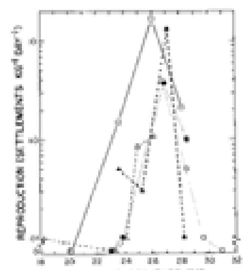


Fungia scutaria regaining pigment at normal temperatures after bleaching.

Experimental coral mortality-temperature relationships



Experimental coral reproduction-temperature relationships

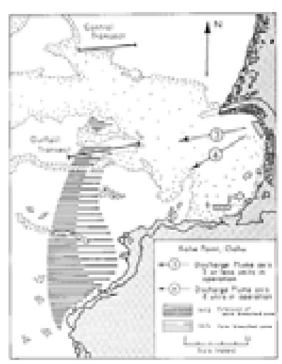


Recruitment and growth of new settlements of the common coral *Pocillopora damicornis* in microcosms at Coconut Island. Jokiel and Guinther 1978

Field studies 1971-72

Kahe Point Electric Generating Station, Oahu, Hawaii

Field studies 1971-72

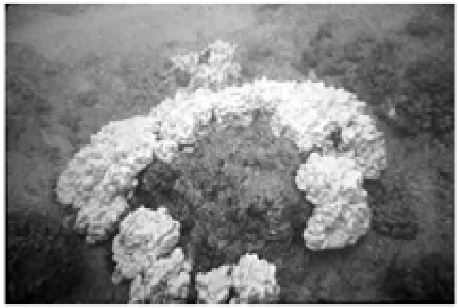


Kahe Point, Oahu

Thermal Plume,
Permanent transects
bleaching and
coral death.

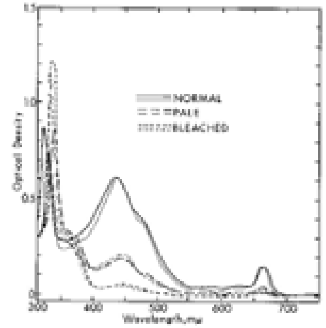
(Jokiel and Coles 1974)

Field studies 1971-72



Kahe Point. Bleached *Porites lobata*, dead *Pocillopora meandrina*.

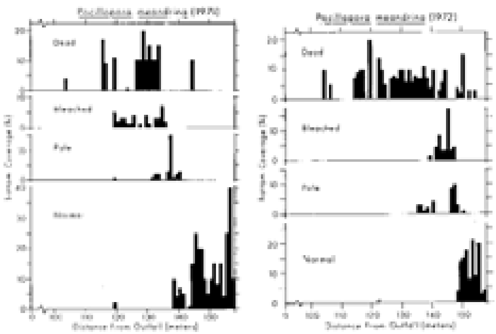
Field studies 1971-72



Spectral criteria for classifying bleached, pale and normal corals.

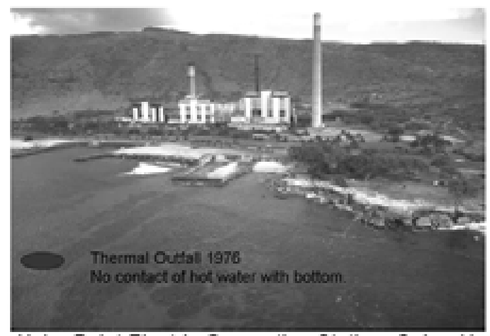
Jokiel and Coles,1974.

Field studies 1971-72



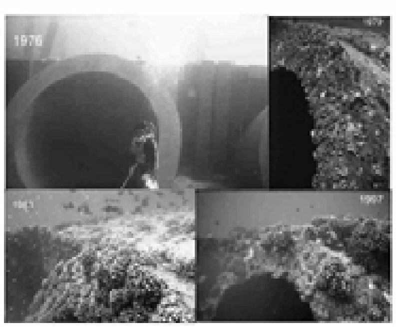
Kahe Point, Oahu - Increasing damage with increased discharge 1971-1972.

Field studies 1971-72



Kahe Point Electric Generating Station, Oahu, Hawaii

Field studies 1971-present

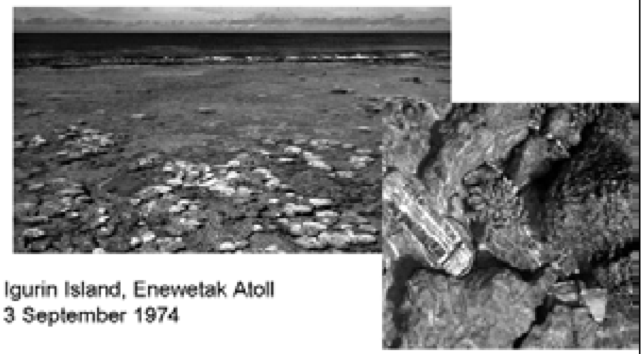


Kahe Point, Oahu - Thermal Outfall

Geographic differences in thermal tolerance.

Enewetak Marine Biological Laboratory, August 1974

Geographic differences in thermal tolerance.



Igurin Island, Enewetak Atoll
3 September 1974

Regional variation in thermal tolerance.

During the summer months corals throughout the world are living within 1-2°C of their upper thermal limit.

Coles, S. L., P. L. Jokiel and C. R. Lewis. 1976. Thermal tolerance in tropical versus subtropical Pacific reef corals. Pac. Sci. 30:156-166.

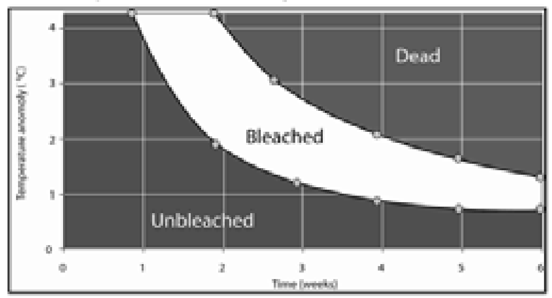
Regional variation in thermal tolerance.

Location	Mean Summer Max. (°C)	Bleaching Threshold (°C)	Increase Above Summer Max. (°C)	Reference
Easter Island	25	27	2.0	Wellington et al. 2001
Sodwana Bay, South Africa	26.5-27.0	27.5-28.8	1.0-1.8	Celliers and Schleyer 2002
Hawaii	27-28	29-30	1.0-2.0	Jokiel and Coles 1990
Gulf of Panama	28	-	-	Glynn 1977
Gulf of Panama	-	30	2.0	Glynn and Cruz 1990
Gulf of Chiriqui	28	-	-	Glynn 1977
Gulf of Chiriqui	-	30	2.0	Glynn and Cruz 1990
Bermuda	28	30	2.0	Cook et al. 1990
Tahiti	28.2	29.5	1.3	Brown 1997
Johnston Atoll	28.6	-	-	US Dept Commerce 1970
Johnston Atoll	-	30.0	1.6	Coles et al. 1997
Enewetak	29-30	31-32	1.0-2.0	Coles et al.
Lizard Island, Australia	29	30	1.0	Hoegh-Guldberg & Smith, 1989
Papua, New Guinea	29	30.3	1.3	Davies et al. 1997
Phuket, Thailand	29.5	30.1	0.6	Brown 1997
Palau	29.7-30	31	1.0 - 1.3	Bruno et al. 2001
Arabian Gulf	34	-	-	Coles 1988
Arabian Gulf	-	35-36	1.0-2.0	Wilkinson et al 1999

Jokiel, P. L. 2004. Temperature Stress and Coral Bleaching. 2004. pp. 401-425 *In* Coral Health and Disease (E. Rosenberg and Y. Loya Eds.). Springer-Verlag, Heidelberg.

How warm is too warm?

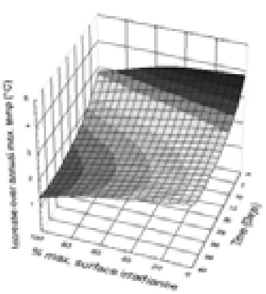
Relationship between intensity and duration of heat stress



Hence the concept of degree heating week (DHW) and degree heating month (DHM)

Relationship between intensity and duration of heat stress in relation to irradiance.

Corals will bleach and die more rapidly at high irradiance than at low irradiance.



Jokiel, P. L. 2004. Temperature Stress and Coral Bleaching. 2004. pp. 401-425 *In* Coral Health and Disease (E. Rosenberg and Y. Loya Eds.). Springer-Verlag, Heidelberg.

How warm is too warm?

Bleaching thresholds vary with:

1. **Geographic region**
2. **Community composition**

M.Mamane

Estimating bleaching thresholds

Thresholds based on average maximum temperatures

- Determine long term average maximum for region
- Determine current local temperature using loggers or real-time weather stations
- Sum anomalies on a daily or weekly basis to determine accumulated exposure (DHW's)
- Bleaching threshold approx. 4 DHW

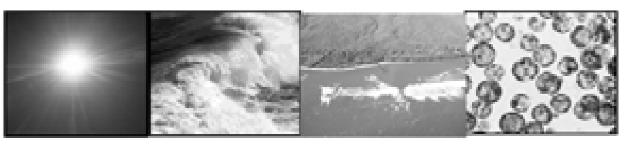
Estimating bleaching thresholds

Thresholds based on past bleaching events

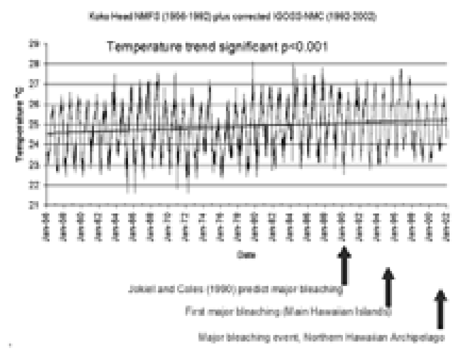
- Gather records of when corals did and did not bleach over previous years at site of interest
- Match bleaching to historical temperature records
- Threshold falls between lowest temperature for bleaching years and highest temperature for non-bleaching years
- Take into account INTENSITY and DURATION
- Also irradiance (cloud cover, turbidity), water motion upwelling, zooxanthella clade type etc.

Thresholds based on experimental data:

- How well do thresholds derived from laboratory apply in the field?
- Many factors interact with bleaching impacts in field:
  e.g. light, water movement, turbidity, local history of acclimation and adaptation.
- Thus controlled laboratory experiments suspported by field observations are especially valuable.

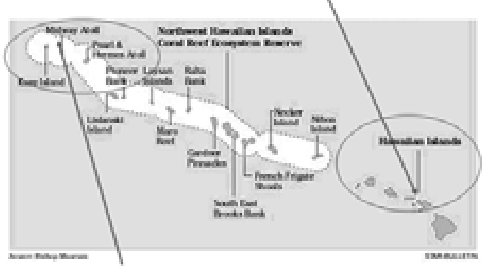


Prediction:



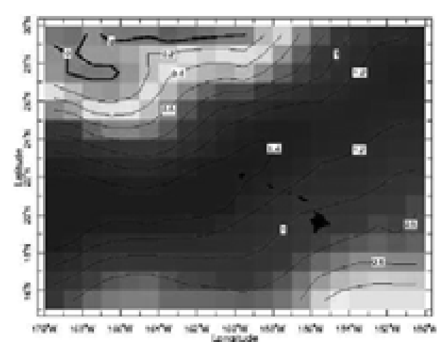
Prediction:

The first mass bleaching occurred in 1996 in the main Hawaiian Islands.



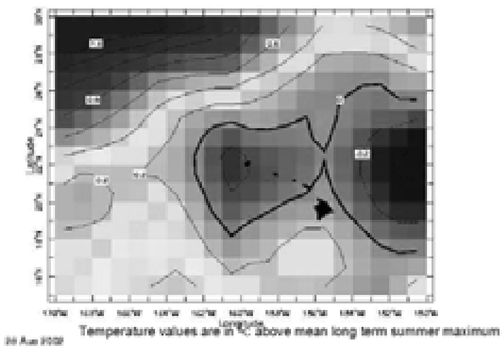
A second major bleaching event occurred in 2002 centered in the northern portion of the Archipelago

Main Hawaiian Island bleaching, 1996



Temperature values are in °C above mean long term summer maximum.

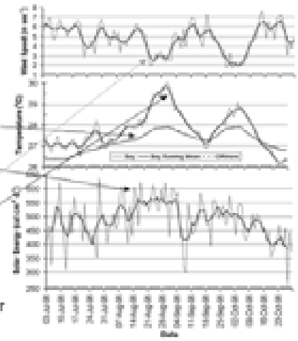
NWHI Bleaching, 2002



How well did thresholds derived from laboratory apply in the field?

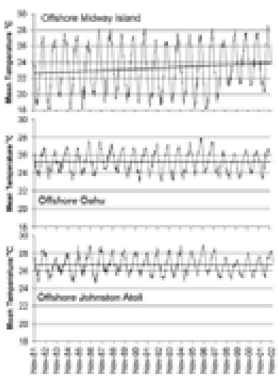
Major factors leading to the 1996 mass bleaching event:

1. Regional offshore positive summer temperature anomaly exceeding +1 °C.
2. High surface irradiance (summer irradiance, low cloud cover).
3. Low wind speed.
4. Restricted water circulation in shallow Kaneohe Bay leads to rapid heating under these conditions.

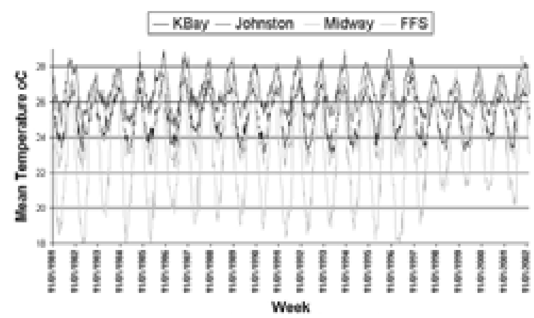


Regional differences in temperature:

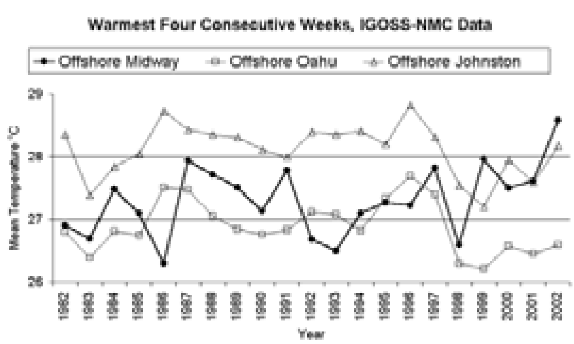
IGOSS-NMC data.
Nov. 81-Nov.02



Regional differences in temperature:



Regional differences in temperature:



Summary 3.1.3

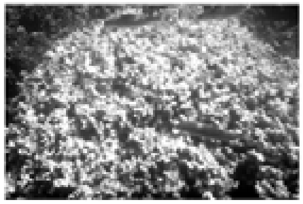
- Scientific evidence established thermal limits for Hawaiian corals by 1976.
- Evidence prevented construction of Heeia electric generating plant in Heeia, Kaneohe Bay, Oahu.
- Evidence forced multi-million dollar construction of a new outfall at Kahe Point Oahu.
- Evidence is sufficient to justify action to prevent future collapse of Hawaiian coral reefs.

Section 3.1.4 Bleaching Assessment Techniques

3.1.4 Assessing Ecological Impacts of Bleaching

Outline of Talk:

1) Techniques for bleaching assessment
2) Special considerations for bleaching assessment compared to normal monitoring
3) Florida Reef Resilience Program (FRRP) monitoring protocol



Bleached *Porties compressa*, Kaneohe Bay, Sept. 1996

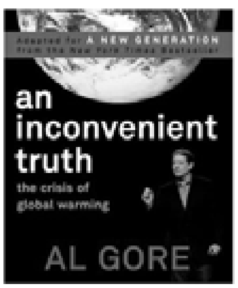
Why do we need to measure bleaching impacts?

1 To make timely and effective management decisions
2 To communicate / educate
3 Answer questions from stakeholders, media, government, concerned public:

'How bad is it?'
'What are the impacts to the reef?'
'What will it mean for the local stakeholder community?'

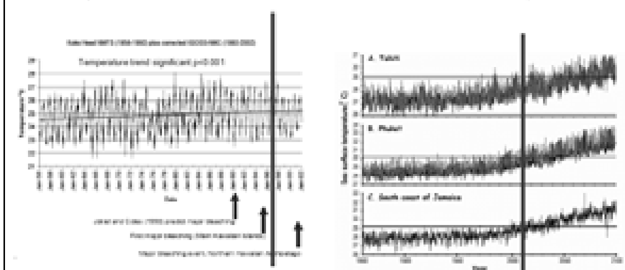
'What does this mean in terms of human survival on the planet?'

Relevance of bleaching to global long term change.



Importance of outreach and education.

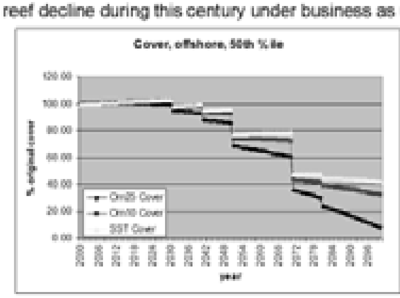
Crossing over the line – coral reefs as the "mine canary".



Coral reefs are the first ecosystems to undergo major damage and can serve to convince the world that drastic action is needed before it is too late for the planet as a whole.
Terry Hughes, Darwin Award Plenary, ICRS 2008

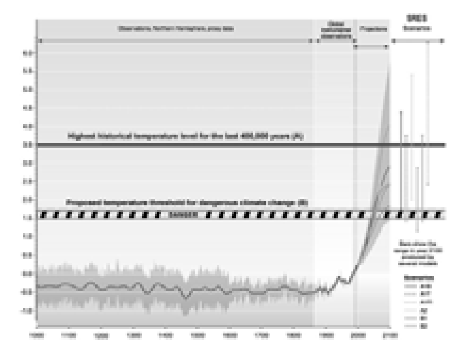
The "COMBO" Model – an example run from Hawaii

Modeled reef decline during this century under business as usual scenario.



Buddemeier, R. W., P.L. Jokiel, K.M. Zimmerman, D.R. Lane, J. M. Carey, G.C. Bohling, J.A. Martinich. (in press) A modeling tool to evaluate regional coral reef responses to changes in climate and ocean chemistry Limnol Oceanogr.

Where are we going? And why are we all in this hand basket?



A Multitude of Survey protocols:

- *CRED surveys in NWHI (Jean Kenyon, Greta Aeby, others)*
- *Great Barrier Reef Marine Park Authority Coral Bleaching Response Plan*
- *Reef Check Bleaching Monitoring Protocol*
- *Australian Institute of Marine Science – coral bleaching index*
- *BLAGRRA: Atlantic and Gulf Rapid Reef Assessment Bleaching Protocol*
- *TNC Florida Reef Resilience Program, Expert Response Protocols*
- *Wildlife Conservation Society Bleaching Assessment Protocol*

SEE MANAGERS GUIDE FOR COMPREHENSIVE LIST

Use existing baseline surveys.

Example of high quality existing baseline data.

Why different survey protocols?

- Different questions/objectives
- Different levels of observers (scientists, rangers, resource users)
- Different resources (financial, time, boat, diving, plane)
- Different spatial scales (small, large)
- Different opportunities for partnership (communities, dive operators, glass bottom boats)

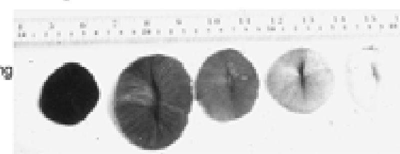
MANAGER'S GUIDE and R2 Toolkit useful to help you develop a protocol

Which methods do we use?

First question: What are your goals?

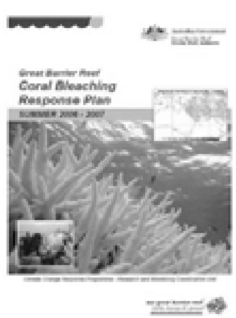
- **Quantifying extent and severity of bleaching**
- **Assessing ecological impacts**
- **Monitoring long-term changes**
- **Raising awareness**
- **Understanding bleaching resistance**

Experimentally bleached *Fungia scutaria*, undergoing Recovery.
Kaneohe Bay 1970



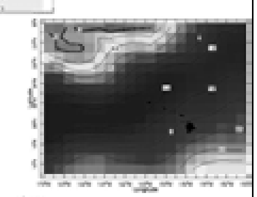
Develop a Plan!

- Case study:
  GBMRPA Coral Bleaching Response Program
- Also:
  - Bali Barat Bleaching Response Plan
  - Florida Keys NMS Bleaching Response Plan



Steps in the Bleaching Response Plan

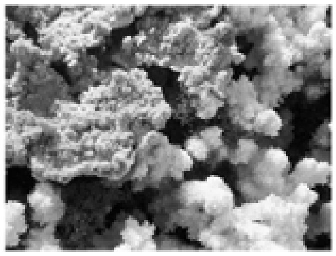
- Early warning
- First Observations
- Broad scale surveys
- Detailed surveys of impacts
  - Immediate
  - Long-term
- Communication



Steps in the Bleaching Response Program

- Early Warning
- First Observations
- Broad scale surveys
- Detailed surveys
  - Immediate
  - Long-term

Based on MG Table 2.3

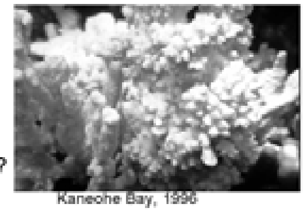


Midway Atoll 2002, photo by Jean Kenyon

First observations

Questions:

- Is bleaching occurring?
- Where is it occurring?
- What proportions and types of corals have been affected?
- How bad is it?
- Do observations match bleaching predictions (e.g. Weather, SST data, Alerts)?



Kaneohe Bay, 1996

First observations - Volunteer Reporting

e.g. BleachWatch (GBR, FKNMS, Bali)

- Tourism/dive operators
- Involves ~10 mins / week
- Resource kit and reports provided
- *"Observe to Conserve"*

BleachWatch
observe to conserve

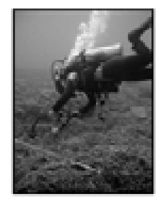
Advantage: Cost effective, large area coverage, awareness

Disadvantages: Often subjective, reliability depends on training

Steps in the Bleaching Response Program

- First Observations
- **Broad scale surveys**
- Detailed surveys of impacts
  - Immediate
  - Long-term

Based on MG Table 2.3



Broad-scale surveys

Questions:

- **Are community reports correct?**
- **Where is bleaching occurring?**
- **What is the total area of reef affected by bleaching?**
- **How bad is the bleaching?**
- **What is the category of extent and severity?**

Broad-scale surveys

Techniques:

- **Timed swims**
- **Boat-based observations**
- **Manta-tow**
- **Aerial surveys**
- **Satellite surveys**

Steps in the Bleaching Response Program


- First Observations
- Broad scale surveys
- **Detailed surveys of impacts**
  - Immediate (Baselines, Coral Impacts)
  - Long-term (Ecosystem Impacts, Recovery)
  - Use of existing network of monitoring sites (CRAMP, CRED, WAP, DAR, others)

Based on MG Table 2.3

Detailed surveys

Questions:

- **What are the local impacts of a mass bleaching event?**
- **What percentage of corals have survived or died from bleaching?**
- **What kinds of corals were most affected by bleaching?**
- **Has the species composition or diversity of a reef changed due to a bleaching event?**

Pocillopora and *Montipora*
Midway Atoll 2002
Photo: Jean Kenyon

Detailed surveys

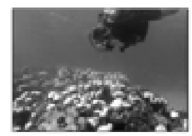
Techniques:

- **Line intercept and point intercept transects**
- **Belt transects**
- **Photo/Video transects**

Florida Reef Resilience Program (FRRP)

FRRP Disturbance Response Monitoring

- **Monitor coral reef health after a disturbance**
- **2005-2007 focused on coral bleaching**
- **Trained experts surveyed corals and bleaching on FL reef tract during peak annual temperatures**
- **Follow-up surveys after moderate/severe bleaching years**
- **Can be used for other disturbances (eg. Hurricanes)**

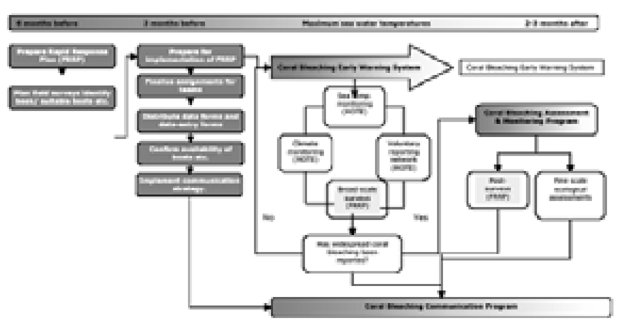



Florida Reef Resilience Program (FRRP)

Field Methods

- **Random sites generated and assigned to teams**
- **1 x 10m belt transects (2/site)**
- **Measure/assess all corals (>=4cm)**
- **Species level identification**
- **Bleaching and disease (visually)**
- **Data entered online**
- **Database queried for results**

Florida Reef Resilience Program (FRRP)



Bleaching response time line.

Choosing the right methods

Manager's Guide Table 2.3, Brown *et al.* 2004.

Table 2.3. Management questions and ecological assessment techniques

Questions	Technique	Description	Advantages/ disadvantages	Data collected
Volunteer and community-based reports				
• Is bleaching occurring? • Where is it occurring? • What proportion and types of corals are affected, and how badly?	Monitoring by volunteers	• A network of volunteers is established to report on conditions at their sites and assess whether or not and to what extent bleaching is occurring. Volunteers might include tourism operators, community members, students, NGO staff, scientists or enforcement officers. • The University of Queensland has developed a colour chart system to help volunteers*.	• Cost-effective method for determining if bleaching is occurring and the extent of bleaching, potentially over a large area. • Depending on volunteer training, data may be quite subjective.	• Presence/absence of bleaching at one or multiple sites • Indication of bleaching progress and severity

Incorporating bleaching monitoring into routine monitoring

Routine/Long term Monitoring

- Establish baseline
- Long-term monitoring
- Demonstrate trends
- Inform management decisions

Coral Bleaching Monitoring

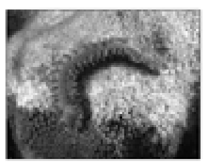
- Early warning - detect impact
- Determine level of impact
- Detect spatial extent
- Identify patterns
- Inform management decisions
- Modify long term monitoring

Special Considerations for Bleaching Assessment

A manager must be skilled at:

- Recognising when a bleaching event is occurring





Special Considerations for Bleaching Assessment

A manager must be skilled at:

- Accurately describing the severity of bleaching

Bleaching severity index

Low

Pale (discoloration of coral tissue)

Partially Bleached (Patches of fully bleached or white tissue)

Bleached (tissue is totally white, no zooxanthellae visible)

High

Special Considerations for Bleaching Assessment

A manager must be skilled at:

- Deciding when to survey
  - **Before** – Easy
  - **During** – Rely on reports
  - **After** – Difficult: Need to wait until mortality issue is resolved to understand full impacts

Need to be ready to go bleaching is imminent: Need a Plan !!!

Precision and statistical power

Repeatability

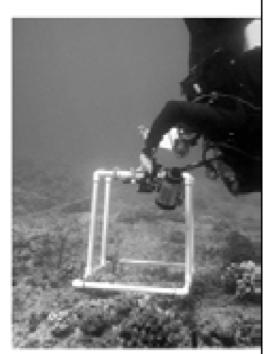
Appropriate length and number of the transects

Number of frames or subsamples

Cover estimation techniques

Observer variation

Time and costs



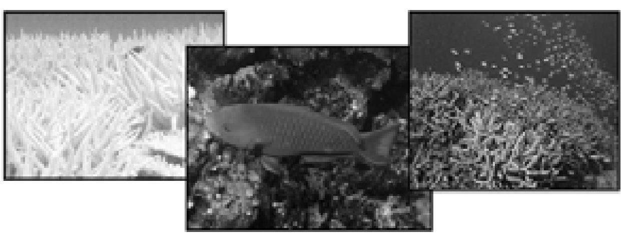
Summary

- There will be increasing opportunities to describe more severe and more frequent bleaching events
- Managers need to assess the extent and severity of bleaching and impacts on ecosystems
- Various approaches to monitoring
  – No right or wrong choice! Only poor statistical design
- Methods used depend on objectives, resources and levels of expertise (no single best method!)
- Best value from integrating existing/routine monitoring with bleaching monitoring
- Develop a Bleaching Response Program to be *ready to go!*

Section 3.2.1 What is Ecological Resilience?

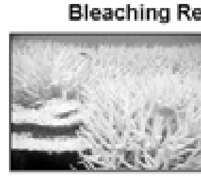
Section 3.2

Ecological Resilience to Climate Change



Section 3.2. Outline

1. **What is Ecological Resilience?**
2. **Factors that Confer Resilience.**
3. **Using Bleaching to Identify Resilient Areas.**
4. **Incorporating Resilience Monitoring into a Bleaching Response Plan.**



Ecological resilience

- Brainstorm: what is it?

3.2.1 What is **Ecological Resilience?**

Ecological Resilience Definition

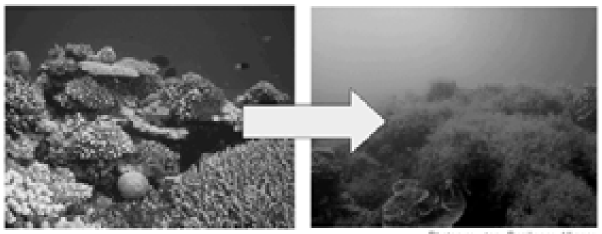
The capacity of an ecosystem to tolerate disturbance without collapsing into a qualitatively different state that is controlled by a different set of processes.

A resilient ecosystem can withstand shocks and rebuild itself when necessary (Resilience Alliance Network)

We aim for a healthy system that can bounce back after major stress

What is Ecological Resilience?

Avoid collapse into a different state with different ecological processes:

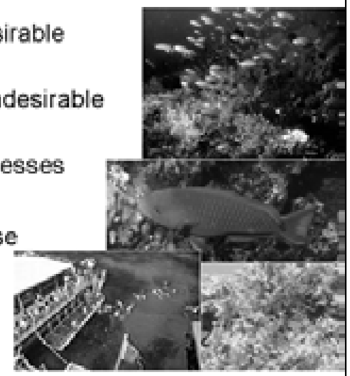


Photos courtesy Resilience Alliance

Promoting resilience to climate change

- Increase stability of desirable states
- Decrease stability of undesirable states
- Maintain functions/processes
- Maintain biodiversity
- Promote sustainable use

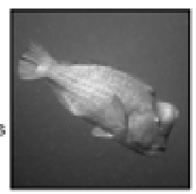
SAME ECOSYSTEM ATTRIBUTES WE HAVE BEEN MANAGING FOR ALL ALONG!



So what does resilience look like?

- High cover
- High diversity
- Low disease
- Good water quality

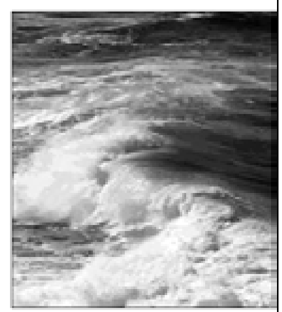
- Broad size/age range
- Corals survived stress
- Good recruitment
- Connectivity & larval sources
- Functional groups



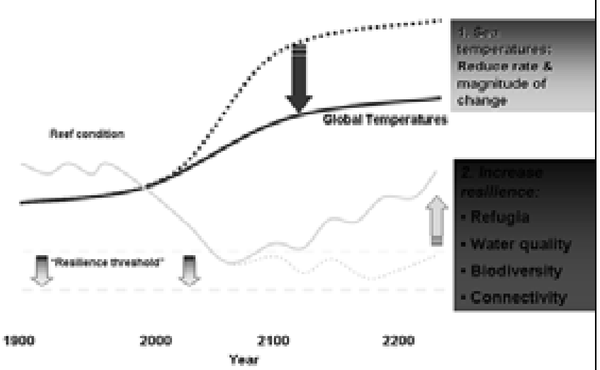
Managing for Resilience – a Strategy to Cope

Resilience provides opportunities to help reefs cope with climate change

Buying time



Managing reefs for resilience



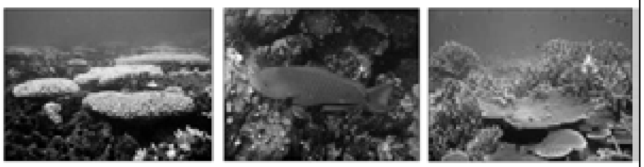
Section 3.2.2 Factors that Confer Resilience

3.2.2 Factors that confer resilience:

Resilience to climate change is not a new concept...

.......we have been managing for resilience all along.

However, there are some **FACTORS** to consider that are specific to resilience in the face of climate change



Factors that confer resilience:

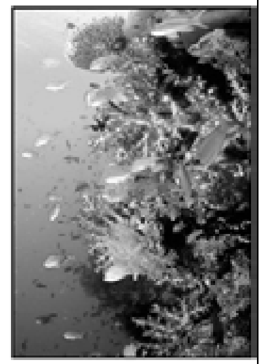
Factors that confer resilience fall into four broad categories:

1) Ecosystem Condition

2) Biological Diversity

3) Connectivity

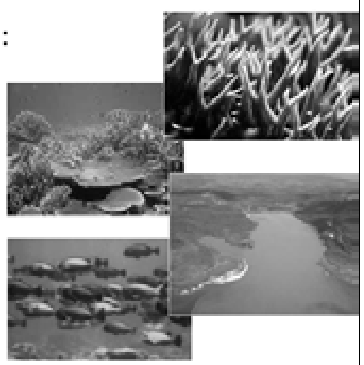
4) Local Environment



Factors that confer resilience:

Ecosystem Condition:

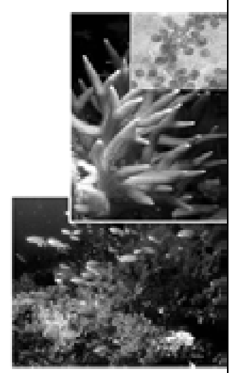
- Coral Health
- Coral Cover
- Water Quality
- Herbivore Abundance



Factors that confer resilience:

Biological diversity:

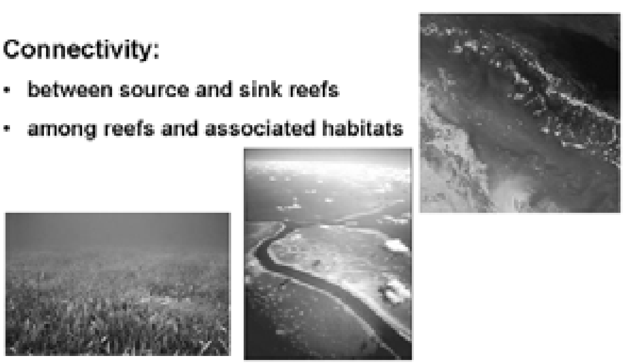
- Diversity of zooxanthellae
- Genetic diversity of corals
- Non-coral species diversity
- Habitat diversity
- Functional redundancy



Factors that confer resilience:

Connectivity:

- between source and sink reefs
- among reefs and associated habitats



Factors that confer resilience:

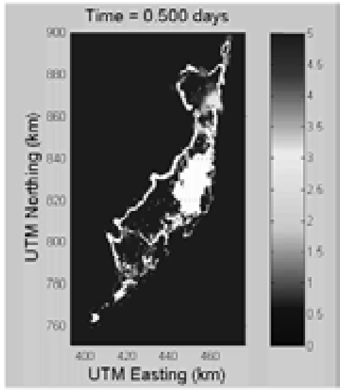
Local Environmental factors:

- Cooling
- Shading
- Screening
- Stress tolerance

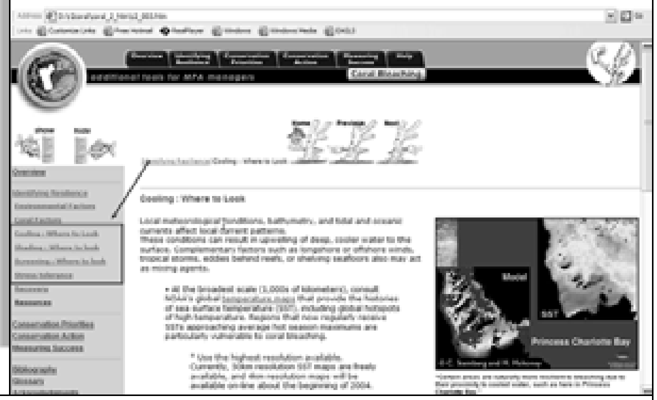
Cooling

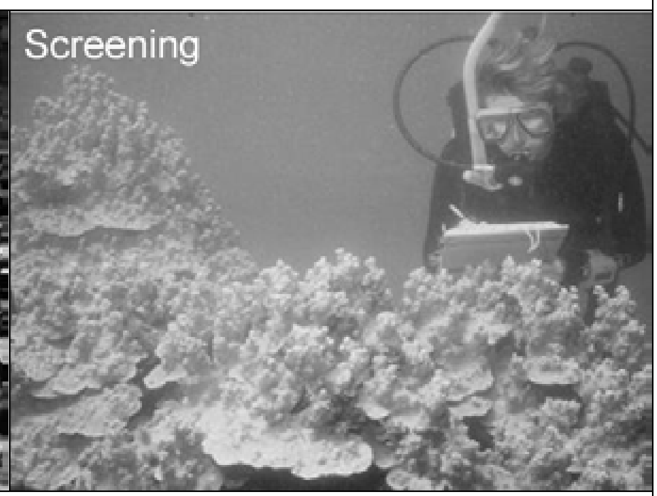
Hydrodynamic models – predict mixing/cooling

(high tech approach)



How can the R2 Toolkit help?



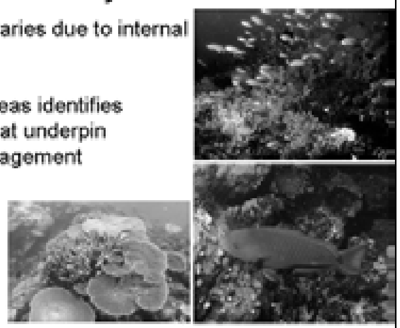


Section 3.2.3 Identifying Resilient Areas

Section 3.2.3 Identifying resilient areas

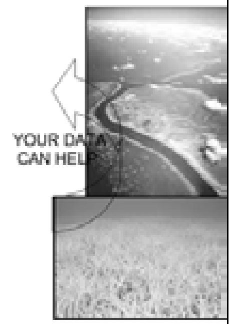
Why do we need to identify resilient areas?

- Bleaching response varies due to internal and external factors
- Identifying resilient areas identifies networks of refugia that underpin resilience-based management



Identifying resilient areas for management

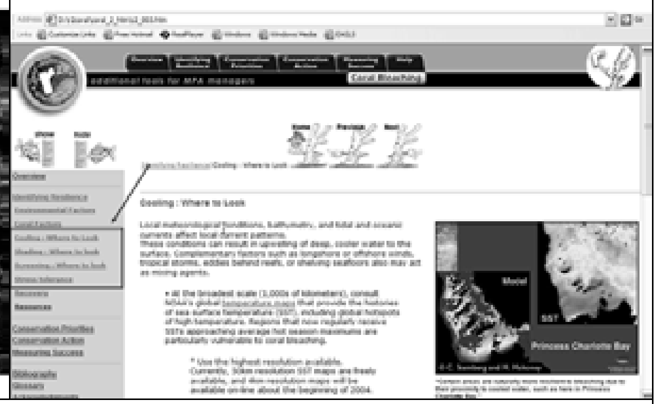
1. PREDICTION:
   Identify factors on *likely* to confer resilience.
   - Data and observations
   - ecological principles
2. OBSERVATION:
   Observe local patterns of bleaching response to warm water events



Identifying resilient areas for management

1. PREDICTION:
   Identify FACTORS on local reefs that are *likely* to confer resilience.
   - Data and observations
   - ecological principles
   - Use R^2 Toolkit to choose factors to examine

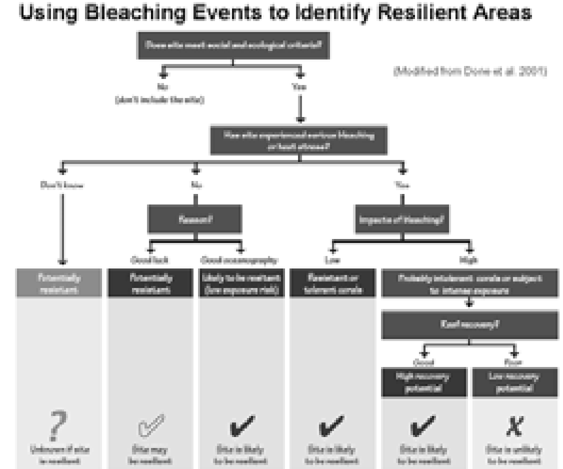
Identifying resilient areas – R2 toolkit

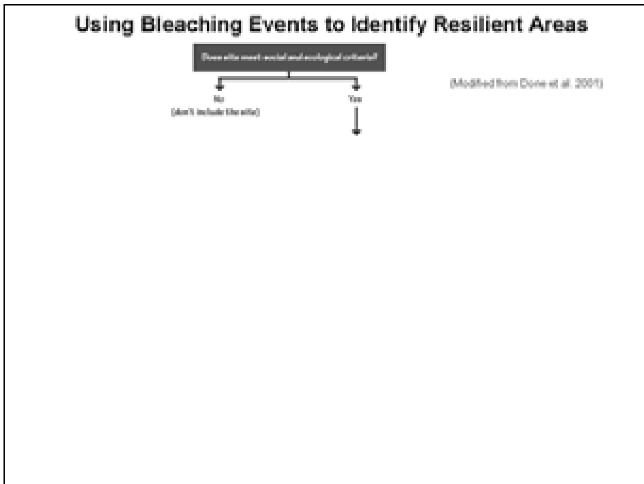


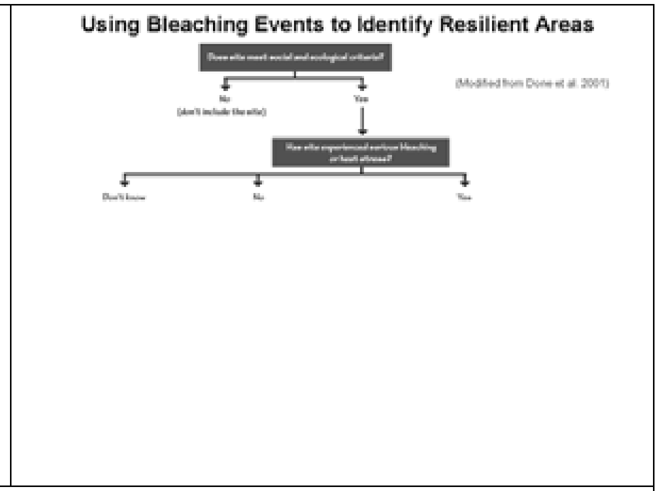
Identifying resilient areas – R2 toolkit

2. OBSERVATION:
   Directly observing local patterns in bleaching response to past warm water events

Using Bleaching Events to Identify Resilient Areas




Using Bleaching Events to Identify Resilient Areas
(Modified from Done et al. 2001)


Using Bleaching Events to Identify Resilient Areas
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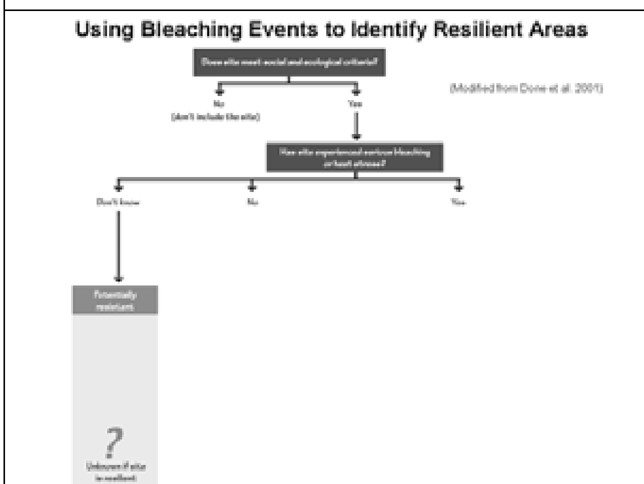
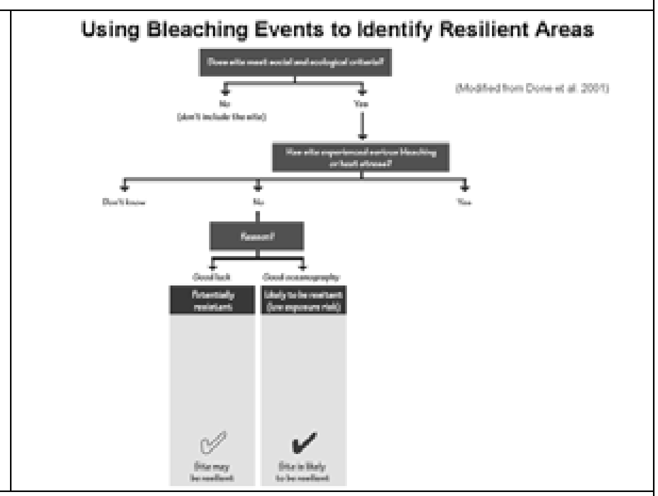
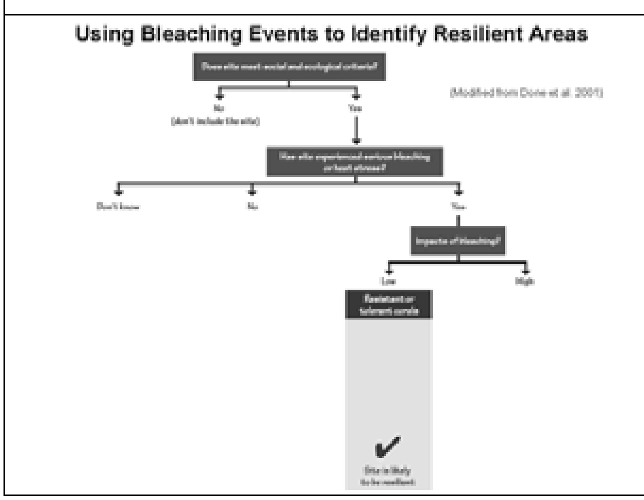
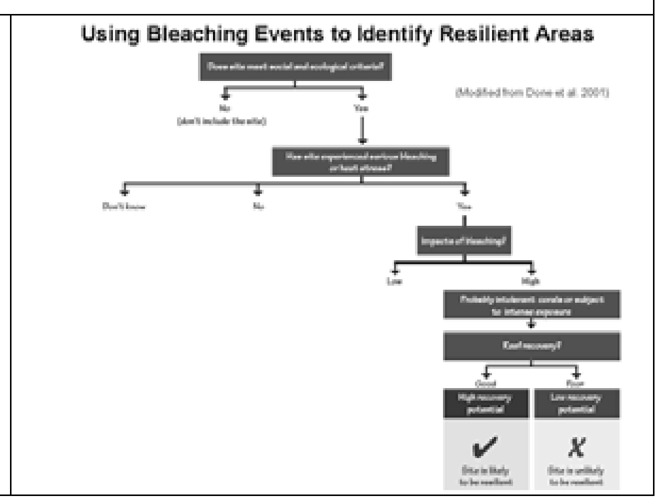

Using Bleaching Events to Identify Resilient Areas
(Modified from Done et al. 2001)


Using Bleaching Events to Identify Resilient Areas
(Modified from Done et al. 2001)


Using Bleaching Events to Identify Resilient Areas
(Modified from Done et al. 2001)


Using Bleaching Events to Identify Resilient Areas
(Modified from Done et al. 2001)

Identifying Resilient Areas

For identified resilient areas:

- Use this information to inform management decisions
- Consider incorporating these areas into your management, weighing up other issues (Module 7)
- Still large gaps in our understanding of resilience factors
- What were the factors present that could have resulted in this resilience?
- Need YOUR data to inform science

Adapting management

- Work to reduce non-climate stressors
- Plan beyond the reef, use a holistic approach
- Include bleaching resilience concepts in planning
- Representation and risk spreading are still the answer to uncertainty
- Include monitoring and hypothesis testing so you can learn and adapt
- Share experiences

Sharing Experiences

IUCN Working Group

on Climate Change and Coral Reefs

(David Obura et al., MacArthur Foundation)

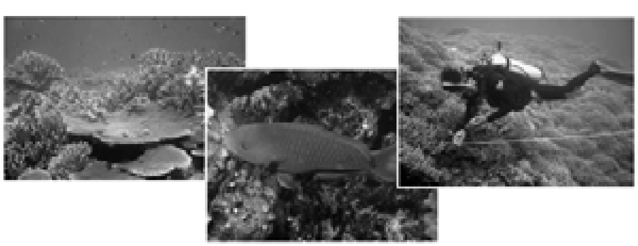
Building a network of resilience test sites

YOU CAN HELP!

Section 3.2.4 Monitoring for Resilience

Section 3.2.4

Monitoring for Resilience



Which factors should we monitor?

Decision based on:

- Importance of factor in local area
- Resources required to monitor factor
- Technical expertise required to monitor factor
- Measurability of factor (proxies, e.g. connectivity)

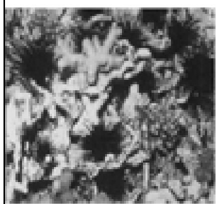
Resilience Factors: State of Knowledge

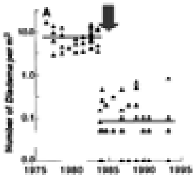
Factors we know confer resilience:

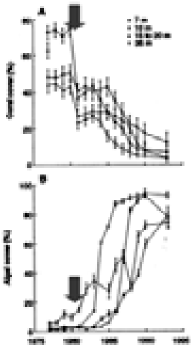
Functional diversity /

Functional redundancy

(Hughes 1994)





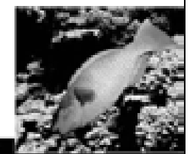


Resilience Factors: State of Knowledge

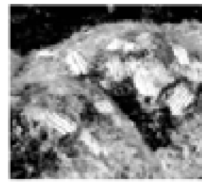
Factors we know confer resilience:

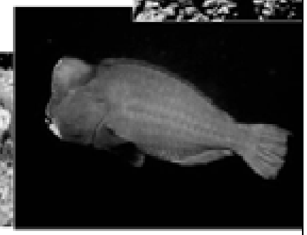
Functional diversity /

Functional redundancy



Bellwood et al. 2003





Resilience Factors: State of Knowledge

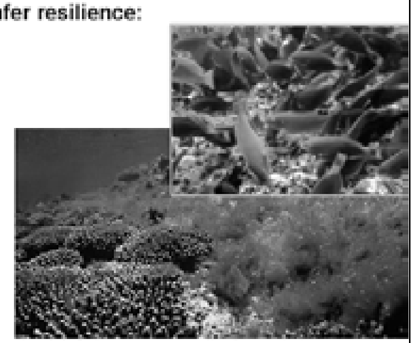
Factors we know confer resilience:

Herbivory

McClanahan et al.

McCook

Hughes et al.

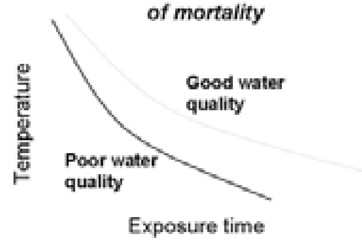


Resilience Factors: State of Knowledge

Factors we know confer resilience:

Water Quality

Ken Anthony



Resilience Factors: State of Knowledge

Factors we know confer resilience:

Shading

(West and Salm 2003)

Resilience Factors: State of Knowledge

Factors that SHOULD confer resilience:

- Connectivity
- Coral cover/age and size distribution
- Low fishing pressure
- Low level of other physical impacts/disturbances
- Water movement
- Low level of bioeroders and disease

What do we actually measure?

Factor

↓

Indicator

↓

Variable

What do we actually measure?

Factor	Condition that confers resilience
↓	↓
Indicator	Characteristic that provides information about each factor
↓	↓
Variable	The actual data that we gather to quantify each indicator

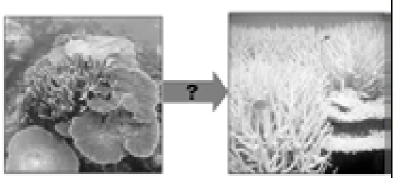
Resistance and Tolerance – Factors

Internal factors

- Reef Resistance to Bleaching
- Areas of high coral cover
- Diversity
- History of survival
- Acclimatization

External factors

- Cooling
- Shading
- Screening
- Flushing



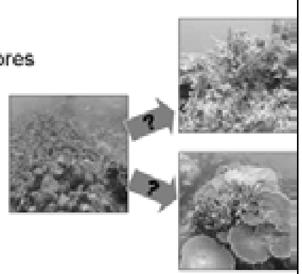
Resistance and Tolerance: Indicators

Internal factors	Indicators
Reef Resistance to Bleaching	Size class structure
Areas of high coral cover	Benthic cover
Diversity	Cover/presence of species
History of survival	Size class structure
Acclimatization	Proxy indicators
External factors	
Cooling	Currents, tides, circulation, waves
Shading	Island/reef slopes, coral community
Screening	Turbidity, water clarity, CDOM
Flushing	Currents, tides, circulation, waves

Recovery potential: Factors

Internal factors

- High remaining coral cover & diversity
- Good recruitment
- 'Healthy' population of herbivores
- Low amounts of bioerosion, corallivores, & coral disease



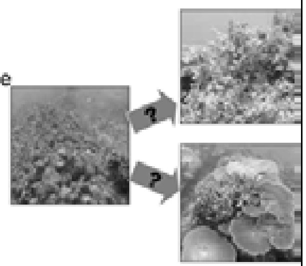
Recovery potential: indicators

Internal factors	Indicators
High remaining coral cover & diversity	Size class/population structure/benthic cover
Recruitment	Recruit abundance, Substrate availability
Herbivory	Herbivorous fish
Low abundance of bioeroders, corallivores, & coral disease	Surveys - urchins, corallibores, coral disease

Recovery potential: Factors

External factors

- Effective management
- Good water quality
- Natural disturbance regime
- Good connectivity
- Factors that concentrate larval supply



Recovery potential: indicators

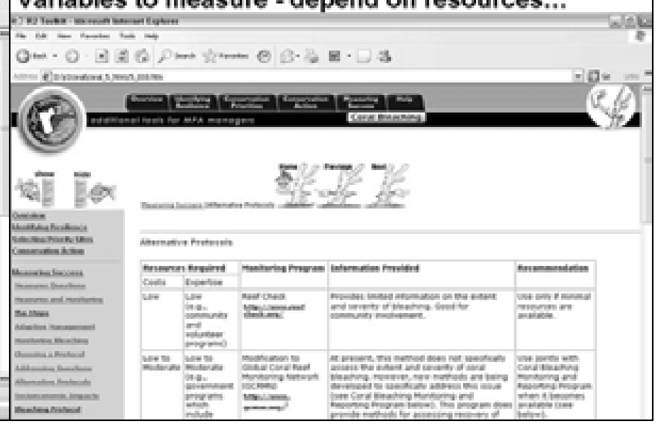
External factors	Indicators
Effective management	Management indicators
Good water quality	Water quality, sedimentation, etc.
Natural disturbance regime	Storms, wave energy, surveys, etc.
Good connectivity	Oceanographic studies
Factors that concentrate larval supply	Oceanographic/research studies

Variables to measure - depend on resources...

Resilience Factor	Resilience Indicator	Variable to monitor
Cooling: physical factors that reduce water temperature	Upwelling	**H-** Tidal mixing models, temp data from loggers, weather stations **L-** Maps, one-off observations of wind and temperature, local knowledge
Flushing: physical factors that increase water movement and promote mixing	Fast current speeds	**H-** Current meters, weather stations **L-** Maps, one-off observations of currents, marked sticks to measure tide, local knowledge

Variables to measure - depend on resources...

Variables to measure - depend on resources...



Proceed with caution!

- Sites that did not bleach during one event may still bleach during the next event for unknown reasons:
  - Warm water events are spatially variable and unpredictable
  - Responses of corals are spatially and temporally variable
- Science underpinning importance of resilience factors is still evolving

Monitoring For Resilience: Summary

- Identifying resilient areas important for informing management decisions
- Identification of sites: Prediction vs Observation
- Many resilience factors still lack evidence: Need your help!
- Use basic management principles in first instance
- Incorporate resilience wherever possible and appropriate
- Be ready to adapt management as more information becomes available

Monitoring to identify Resilient Areas

FIELD ACTIVITY:

Identifying Resilient Reef Areas

Data sheets

Maps

Monitoring to identify Resilient Areas

ABOVE-WATER RESILIENCE DATA FACTOR:	Unknown	None	Low	Medium	High
Upwellings: Rate the extent to which this site is impacted by upwelling					
Water Movement: Rate the extent to which factors that increase water movement and promote mixing are present at this site (eg. Peninsulas/channels, large tides, exposure to winds and waves)?					
Reduction in Light Stress: Rate the extent to which incident light is **reduced** at this site (eg. High islands, rock overhangs, high natural turbidity, steep depth gradients)					
Reduced Air Exposure: Rate the amount corals at this site that **stay submerged** at low tide					
Hot Water Events: Rate the extent to which this site has been previously exposed to hot water and survived					
Temperature Variability: Rate the natural temperature variability at this site					
Connectivity: Rate the extent to which neighbouring upstream reefs are close enough to this site to provide propagules following a disturbance					
Mature Coral Colonies: Rate the abundance of large (mature) coral colonies					
Free from Fishing Pressure: Rate the extent to which this site is **free from** fishing impacts					
Free from other Physical Impacts: Rate the extent to which this site is **free from** exposure to, or impacted previously by other physical factors (eg. anchoring, destructive fishing, diving impacts, extraction)					
Totals					

Monitoring to identify Resilient Areas

BELOW-WATER RESILIENCE DATA: FACTOR:	Unknown	None	Low	Medium	High
Upwelling: Rate the extent to which this site is impacted by upwelling					
Large-scale water movement: Rate the extent of water movement at this site caused by currents and wave action.					
Fine-scale water movement: Rate the degree of **topographic complexity** at this site that might affect small-scale water movement and bleaching susceptibility					
Reduced Light Stress: Rate the extent to which physical factors exist at this site that may work to reduce light stress (eg. high natural turbidity, steep reef profiles).					
Coral Cover: Rank the coral cover at this site.					
Resistent/Tolerant Corals: Rate the abundance of resistant/tolerant coral species.					
Coral Diversity: Rate the coral diversity at this site.					
Mixed size-class distribution: Rate the extent to which this site is characterised by a mixed size-class distribution of corals.					
Abundance of mature corals: Rate the abundance of large (mature) coral colonies					
Substrate stability: Rate the extent to which the substrate at this site is stable (lots of hard, consolidated substrate versus loose rubble).					
Substrate availability: Rate the availability of hard substrate for coral recruitment (e.g. amount of free substrate not covered in macro-algae).					
Free from contamination/pollution: Rate the extent to which this site is **free from** exposure to pollution (nutrients, waste etc.)					
Free from sedimentation: Rate the degree to which this site is **free from** sources of sedimentation/siltation					
Free from Other Physical Impacts: Rate the extent to which this site is **free from** physical impacts (eg. anchoring, destructive fishing, diving impacts, extraction)					