Reef Resilience and Climate Change:
A Workshop for Coral Reef Managers

Location
Date
(adapted from Guam 2009 workshop)

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Definitions

Acclimatization: Acclimatization refers to phenotypic changes by an organism to stresses in the natural environment that result in the readjustment of the organism's tolerance.

Accretion: Growth by external addition of new matter.

Adaptive Management: The process of changing a management strategy in response to measuring its success.

Agricultural Run-off: The drainage of water from agricultural land.

AVHRR: Advanced Very High Resolution Radiometer, a sensor that is used to measure sea surface temperature from satellites.

Bathymetry: Measurement of the depth of the sea floor below sea level.

Belt Transect: A unit of data collection using transect lines of a fixed width.

Biodiversity: The number of different species present in a given environment (species diversity). Or, the number of different ecosystems present in a given environment (ecological diversity).

Bioerosion: Erosion caused by living organisms.

Biogeographic: Refers to the distribution of biodiversity over space. A biogeographic region is a geographic area with similar dominant plants, organisms and prevailing climate conditions.

Biota: Living organisms.

BOFFF: The abbreviation for Big Old Fat Fertile Female. BOFFFs are more biologically valuable due to their age and reproductive abilities, and removing them from the system is more detrimental than removing younger, non-reproductive fish.

Bleaching: See Coral bleaching.

Bleaching threshold: The temperature above which corals experience thermal stress that can lead to bleaching; defined as 1°C above the maximum monthly mean.

Catchment: An area that catches water.

Calcium Carbonate: The mineral laid down by a coral to create the hard structure surrounding the organism.

Clades: A clade is a term used to distinguish a taxonomic group that consists of a common ancestor and all descendents (cladograms are graphical depictions of these relationships; see Phylogenetic).

Climate: Long-term characteristics of weather.

Climate Change: The long-term fluctuations in temperature, precipitation, wind, and all other aspects of the Earth's climate. It is also defined by the United Nations Convention on Climate Change as "change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".

Colony Integration: Influences the degree to which a whole colony responds to thermal stress. Characteristics of colony integration include polyp dimorphism, intra-tentacular budding and complex colony morphology. Species with high colony integration are predicted to result in a greater whole-colony response to increased temperatures than species with low colony integration.

Connectivity: Natural linkages among reefs including ocean currents, larval dispersal, spawning patterns, and movements of adult fishes. Connectivity is an important part of dispersal and the replenishment of biodiversity on reefs damaged by natural or human related agents.

Contiguous: Touching area.

Contiguous Habitats: Habitats that share a boundary.

Cooling: Local oceanographic conditions such as vertical mixing of heated surface waters with cooler deeper water that can reduce temperature stress.

Coral bleaching: The paling of corals resulting from a loss of symbiotic algae. Bleaching occurs in response to physiological shock in response to abrupt changes in temperatures, salinity and turbidity. (see also Mass coral bleaching).

Coral Recruit: Settlement of a coral larvae to a permanent location.

Corallivorous: Organisms that consume coral.

Cryptic: Hidden or difficult to see.

CPUE: Catch Per Unit Effort, the number of fish caught per unit time/effort.

Deforestation: The act of cutting down trees within a given forested habitat.

Desiccation: To dry out.

Destructive Fishing: Using cyanide, dynamite, or other methods that cause coral breakage to kill all reef life (including corals, other invertebrates, as well as unmarketable species).

DHW (Degree Heating Weeks): A measurement that combines the intensity and duration of thermal stress in order to predict coral bleaching.

Distant Linked Habitats: Non contiguous habitats linked by connectivity.

Ecoregion: An area that contains a distinct assemblage of communities and species.

Ecosystem Resilience: The ability of an ecosystem to maintain key functions and processes in the face of stresses or pressures by either resisting or adapting to change.

Ecotourism: Responsible travel to natural areas that conserves the environment and sustains the well-being of local people. (The International Ecotourism Society)

Eddy: A current, as of water or air, moving contrary to the direction of the main current, especially in a circular motion.

Electromagnetic Spectrum: Energy that travels through space in the form of waves. The highest frequencies in the spectrum of electromagnetic radiation are gamma-rays; the lowest frequencies are radio waves. All electromagnetic radiation travels at the speed of light. Shorter wavelength radiation (e.g., ultraviolet) carries more energy and is likely to be more harmful to living tissue.

El Niño: An irregular variation of ocean current that from January to March flows off the west coast of South America, carrying warm, low-salinity, nutrient-poor water to the south. It is associated with the Southern Oscillation. These two effects are known as the El Niño Southern Oscillation (ENSO).

Eddy: A current, as of water or air, moving contrary to the direction of the main current, especially in a circular motion.

Energy Regime: Refers to the level of energy that characterizes a location. For example, a site on the leeward side of an island would have a lower energy regime because the influence of the wind on a daily basis is minimal.

Exposure: Describes the level of being exposed to physical forces such as high wave energy, wind, and strong currents. If an area is surrounded by islands with limited influence from waves, wind, and currents, its level of exposure is minimal.

Extractive (Non-Extractive): Taking something out of an environment versus leaving it in place. For example, food fishing is extractive, but catch and release fishing, snorkeling and diving, which leave the fishes in the environment, are non-extractive.

Fecundity: Refers to the potential reproductive capacity of an organism.

Functionally linked habitats Connected environments that are intended to conserve "all". biodiversity in an area- typically large and usually include both aquatic and terrestrial targets.

GBRMPA: Great Barrier Reef Marine Park Authority

Genetic Diversity: Genetic variation within a species.

GOES (Geostationary Operational Environmental Satellite): Geostationary satellites operated by NOAA. Hover at an altitude of about 36,000 km to give continuous data for one fixed area of the Earth's surface and lower parts of a given surface.

GPS: Global Positioning System; An electronic unit that receives satellite signals that tell your specific position in latitude and longitude.

HotSpot: A satellite product that highlights areas where the current sea surface temperature is above the mean temperature for the warmest month. May indicate a risk for coral bleaching.

Infrared Radiation: The part of the electromagnetic spectrum that has energy levels just below visible light. This is felt as radiant heat, and is sensed by the AVHRR sensor on NOAA's satellites.

Integrated Coastal Management: A continuous and dynamic process by which decisions are taken for the sustainable use, development, and protection of coastal and marine areas and resources.

La Niña: A phenomenon characterized by unusually cold ocean temperatures in the eastern Equatorial Pacific, compared to El Niño, which is characterized by unusually warm ocean temperatures in the eastern Equatorial Pacific.

Larval Duration: Pelagic larval duration refers to the amount of time the larvae spend in the open ocean before settlement on the reef.

Local Extinction: The complete loss of an organism in a specific part of its range.

Marine Protected Area(MPA): Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment (IUCN definition).

Marine Protected Area Network: An MPA network can include zones that are designed for different levels of use and extraction. For example, within the MPA network, no-take zones can be strategically placed to prohibit harvest. Multiple-use MPA zoning, including no-take areas, provides a way to accommodate multiple uses (e.g., recreational fishing, commercial fishing, tourism, etc.) and balances the trade-offs between sustainable use and conservation.

Marine Tenure: Locally specified entitlements to marine territories and resources claimed and exercised by the 'guardians' of those territories and resources.

MARXAN: Computer software available at no charge that provides decision support for those designing marine reserves or networks of reserves. It has become the most utilized conservation planning tool in the world.

Mass coral bleaching: (See also coral bleaching) Coral bleaching extending over large distances (often affecting reef systems spanning tens to hundreds of kilometres) as a result of anomalously high water temperatures.

Migration Corridors: Many large marine animals (i.e., whales, predatory fish, turtles, etc.) follow set routes when they migrate (for feeding, nesting, birthing, or breeding purposes) from one area to another. These routes are referred to as migration corridors.

MMM (Maximum Monthly Mean) Temperature: in other words, the average temperature for the warmest month of the year.

Mortality: The rate at which a particular species or population dies.

Mutualistic Relationships: Biological interaction between two species where each derives a benefit from the other.

NGO: Non-Governmental Organization.

NOAA: The U.S. National Oceanic and Atmospheric Administration.

Ocean Acidification: The declining pH (increased acidification) of the oceans due to increased CO2 emissions globally.

Ocean Neighborhood: The area centered on a set of parents that is large enough to retain most of the offspring of those parents.

Pathogen: An organism which causes disease within another organism.

Pelagic Planktonic Larvae: Larvae of planktonic organisms that are located in the open ocean.

Phenotypic Plasticity: Refers to non-genetic variation in organisms in response to environmental factors.

Photosynthetically Active Radiation: Electromagnetic radiation in the wavelengths λ = 400-700 nm (the visible wavelengths and the spectrum used by plants for photosynthesis) that is absorbed by the chlorophyll molecule.

Phylogenetic: Pertains to the evolutionary development of an organism.

Pigment: A compound that gives color to tissue.

Planktivorous: Organisms that consume plankton.

POES (Polar Operational Environmental Satellite): Polar-orbiting satellites operated by NOAA. Orbit the earth at an altitude of about 850km to give global coverage every day and lower parts of a given surface.

Pond-Effect: Wide temperature fluctuations in back-reef lagoons, especially shallow lagoons behind fringing reefs.

Promontory: A high ridge of land or rock jutting out into a body of water.

Refugia: 1. An area that has escaped ecological changes occurring elsewhere and so provides a suitable habitat for relict species. 2. An area of relatively unaltered climate that is inhabited by plants and animals during a period of continental climatic change (e.g., glaciation) and remains as a center of relict forms from which a new dispersion and speciation may take place after climatic readjustment. 3. Secure areas that are protected by natural factors and human intervention from a variety of stresses. They function as reliable sources of seed.

Relief (High or Low, Mapped): The differences between elevation and slope of higher and lower parts of a given surface.

Remote Sensing: Measuring some property of an object from a distance, without touching the object itself.

Replication: The process by which multiple samples of any habitat types are secured in a network of protected areas. Replication helps to spread the risk of any large-scale event destroying all protected examples of any habitat type.

Representation: The inclusion of a full range of habitat types into a protected area system. Representation of all habitat types helps to ensure that the full complement of species for that habitat type is protected.

Resilience to bleaching: Coral colonies bleach and partially or entirely die, but the coral community recovers rapidly to its former state. Resilient reefs should be managed to maintain conditions that facilitate successful coral recruitment and recovery.

Resistance: The capacity of an organism or a tissue to withstand the effects of a harmful environmental agent. Resistance to bleaching is exhibited when coral colonies do not bleach, or bleach but don't die. This may vary among different parts of a reef and between different reef communities.

Resistance to bleaching: Coral colonies don't bleach or bleach but don't die. Resistant reefs play a critical role in reef survival by providing a reliable source of larvae which can recruit to and enable recovery of affected areas.

Salinity: Measure of salt per unit of water usually measured in parts per thousand (seawater is generally around 35 parts per thousand).

Satellite: An object that goes around (orbits) a larger object, such as a planet.

SBA (**Satellite Bleaching Alert):** These free automatic e-mails are sent by NOAA to warn of elevated temperatures that may lead to coral bleaching.

Screening: Screening by suspended or dissolved matter reduces sunlight penetration and may reduce bleaching.

Sediment: Soil or particulate organic and inorganic matter carried in the water.

Sedimentation: The settling of particulate matter.

Shading: Reduced exposure to the harmful effects of sunlight. Examples include high island shadow or overhanging vegetation.

Sink Area: The area to which eggs and larvae disperse and settle.

Site Conservation Planning: Planning methodology which places sites in their larger ecological context; setting conservation priorities and strategies to conserve both single and multiple conservation areas, taking direct conservation action; and measuring conservation success.

SocMon Guidelines: A set of guidelines for establishing a socioeconomic monitoring program at a coastal management site. The guidelines provide a prioritized list of socioeconomic variables useful to managers, questions for data collection, and tables for data analysis.

Social Resilience: The resilience of communities to adapt to and withstand institutional, environmental and economic changes in their particular geography. Often these changes take the form of policies or regulations, with more resilient communities more likely to comply and sustain change.

Source Area: The area from which eggs and larvae originate to supplement populations down current.

Species Diversity: The number of different species present in a given environment.

Spillover: Spillover from an MPA accounts for two types of movements outside the MPA: (1) adults and juvenile animals swim into adjacent areas, and (2) young animals and eggs can drift out from the MPA into the surrounding waters.

Spur and Groove: The series of gullies divided by higher spurs that cross reefs at right angles below the reef crest.

SST: Sea surface temperature.

SST Anomaly: The difference between the current sea surface temperature and a long-term average.

Stakeholder: Any person with a vested interest in the natural resources of concern (e.g., coral reefs).

Stress Tolerance: The response of organisms to stressful conditions that have been repeatedly exposed to a stress, such as an exposed reef flat exposed to warm waters, that may result in a natural tolerance against bleaching.

Stressor: A physical, chemical or biological factor that adversely affects organisms; an agent, condition or similar stimulus that causes stress to an organism.

Stress Tolerance: The response of organisms to stressful conditions that have been repeatedly exposed to a stress, such as an exposed reef flat exposed to warm waters that may result in a natural tolerance against bleaching.

Susceptibility to bleaching: How easily corals are influenced or affected by bleaching.

Symbiotic Algae: Zooxanthellae are tiny symbiotic algae that provide food and oxygen to the coral, allowing their host to direct more energy toward constructing its calcium carbonate skeleton. Bleached corals lose their zooxanthellae and turn white (see also Zooxanthellae).

Synergistic: Producing a combined effect greater than the same agents used separately.

Thermal Stress: Adverse stress caused to an organism by elevated temperature.

Thermohaline Circulation (THC): Large-scale ocean circulation patterns that are driven by global density gradients that result from both temperature (thermo) and freshwater inputs that alters the salinity of the water (haline).

Tolerance (Thermal, Stress): The ability to survive and grow in the presence of normally toxic conditions (i.e. Heat)

Topographical: The characteristics describing the physical features of the environment.

Transect: Typically a straight line across an area along which ecological measurements are taken.

Trophic Structure: The relationship of an organism to other organisms in the context of a food web (trophic refers to an organisms assignment to different trophic levels, i.e., consumers, producers, decomposers, etc.).

Turbid (or turbidity): Limited visibility due to particulate matter suspended in the water; murky.

Turbulence: Small-scale non-directional water movements.

Upwelling: Movement toward the surface of deeper waters, bringing cooler waters with nutrients to the surface.

UTM (Coordinates): Universal Transverse Mercator (UTM) Coordinates measure in meters east and north from two perpendicular reference baselines.

Waypoint: A point of latitude and longitude given when using a GPS unit to map an area.

Zooxanthellae: Symbiotic algae (in the dinoflagellate genus *Symbiodinium*) that lives in the tissues of coral polyps and other host animals. The tiny photosynthetic organisms provide both nutrients and oxygen to the corals and other host animals in which they live (see also symbiotic algae).

Also See NOAA's CoRIS coral reef glossary for more definitions:
http://coris.noaa.gov/glossary/

Module 1: Basics of Coral Reefs and Climate Change

Section 1: Global Climate Change

Learning Objectives

By the end of this module you will have:

- An update on current scientific knowledge on climate change
- An understanding of the causes of mass bleaching
- A grounding in bleaching physiology
- An understanding of ocean acidification and how it may affect reefs
- A background on the emerging connection between climate and coral disease

Background

(http://www.ncdc.noaa.gov/oa/climate/globalwarming.html) Human activity has been increasing the concentration of greenhouse gases in the atmosphere (mostly carbon dioxide (CO_2) from combustion of coal, oil, and gas; plus a few other trace gases). There is no scientific debate on this point. Pre-industrial levels of carbon dioxide (prior to the start of the Industrial Revolution) were about 280 parts per million by volume (ppmv), and current levels are greater than 380 ppmv and increasing at a rate of 1.9 ppm yr-1 since 2000. The global concentration of CO_2 in our atmosphere today far exceeds the natural range over the last 650,000 years of 180 to 300 ppmv. According to the IPCC Special Report on Emission Scenarios (SRES), by the end of the 21st century, we could expect to see carbon dioxide concentrations of anywhere from 490 to 1260 ppm (75-350% above the pre-industrial concentration).

Global surface temperatures have increased about 0.74°C (plus or minus 0.18°C) since the late-19th century, and the linear trend for the past 50 years of 0.13°C (plus or minus 0.03°C) per decade is nearly twice that for the past 100 years. The warming has not been globally uniform. Some areas (including parts of the southeastern U.S. and parts of the North Atlantic) have, in fact, cooled slightly over the last century. The recent warmth has been greatest over North America and Eurasia between 40 and 70°N. Lastly, seven of the eight warmest years on record have occurred since 2001 and the 10 warmest years have all occurred since 1995.

Global mean sea level has been rising at an average rate of 1.7 mm/year (plus or minus 0.5mm) over the past 100 years, which is significantly larger than the rate averaged over the last several thousand years. Depending on which greenhouse gas increase scenario is used (high or low) projected sea-level rise in the next 100 years is projected to be anywhere from 0.18 (low greenhouse gas increase) to 0.59 meters for the highest greenhouse gas increase scenario. However, this increase is due mainly to thermal expansion and contributions from melting alpine glaciers, and does not include any potential contributions from melting ice sheets in Greenland or Antarctica. Larger increases cannot be excluded but our current understanding of ice sheet dynamics renders uncertainties too large to be able to assess the likelihood of large-scale melting of these ice sheets. Healthy coral reefs can probably grow fast enough to keep up with moderate rates of sea level rise. There is some concern that reduced light availability may be a problem, especially for species that grow in deeper areas that may already be light limited. The biggest concern is that other climate factors, especially bleaching and ocean acidification, have been shown to reduce coral growth rates. Slower-growing corals may not be able to keep up with rising sea levels.

(http://www.pmel.noaa.gov/co2/OA/background.html) The oceans have absorbed approximately 525 billion tons of carbon dioxide from the atmosphere, or about one third of the anthropogenic carbon emissions released. This absorption has benefited humankind by significantly reducing the greenhouse gas levels in the atmosphere and minimizing some of the impacts of global warming. However, the ocean's uptake of carbon dioxide is having negative impacts on the chemistry and biology of the oceans. Hydrographic surveys and modeling studies have revealed that the chemical changes in seawater resulting from the absorption of carbon dioxide are lowering seawater pH. The pH of ocean surface waters has already decreased by about 0.1 units from an average of about 8.21 to 8.10 since the beginning of the industrial revolution. Estimates of future atmospheric and oceanic carbon dioxide concentrations, based on the Intergovernmental Panel on Climate Change (IPCC) CO_2 emission scenarios and coupled ocean-atmosphere models, suggest that by the middle of this century atmospheric carbon dioxide levels could reach more than 500 ppm, and near the end of the century they could be over 800 ppm. This would result in an additional surface water pH decrease of approximately 0.3 pH units by 2100.

When CO_2 reacts with seawater, the reduction in seawater pH also reduces the availability of carbonate ions, which play an important role in shell formation for a number of marine organisms such as corals, marine plankton, and shellfish. This phenomenon, which is commonly called "ocean acidification," could have profound impacts on some of the most fundamental biological and geochemical processes of the sea in coming decades. Some of the smaller calcifying organisms are important food sources for higher marine organisms. Declining coral reefs due to increases in temperature and decreases in carbonate ion would have negative impacts on tourism and fisheries. Abundance of commercially important shellfish species may also decline and negative impacts on finfish may occur. This rapidly emerging scientific issue and possible ecological impacts have raised serious concerns across the scientific and fisheries resource management communities.

Worksheet or Activity

Discussion: What indications of Climate Change have you observed in your region?

What habitats do you manage that are susceptible to Climate Change?

On-the-Web

Intergovernmental Panel on Climate Change
http://www.ipcc.ch/

NOAA "Frequently Asked Questions" on climate change
http://www.ncdc.noaa.gov/oa/climate/globalwarming.html

NOAA background on Ocean Acidification
http://www.pmel.noaa.gov/co2/OA/background.html

NOAA ocean acidification tutorial
http://coralreefwatch.noaa.gov/satellite/oa/description/oaps_intro_oa.html

Sea Level Rise explorer in Google Maps
http://www.globalwarmingart.com/wiki/Special:SeaLevel

Publications and References

Blanchon, P. A. Eisenhauer, J. Fietzke, and V. Liebetrau. 2009. Rapid sea-level rise and reef back-stepping at the close of the last interglacial highstand. *Nature* 458: 881-884.

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi and M.E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318(5857): 1737-1742.

IPCC 2007. *Climate Change 2007: The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate

Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Raupach, M.R., G. Marland, P. Ciais, C. Le Quere, J.G. Canadell, G. Klepper, and C.B. Field. 2007. Global and regional drivers of accelerating CO_2 emissions. *Proceedings of the National Academy of Science (PNAS)* 104(24):10288-102093.

Stern, N. 2007. *The Economics of Climate Change: The Stern Review*. Cambridge University Press, Cambridge, United Kingdon, 712 pp.

Slides

Section 2: Rising Temperature, Mass Coral Bleaching & Bleaching Weather

Learning Objectives

By the end of this module you will have:

- A background in rising sea surface temperatures around the world
- An understanding of the connection between environmental conditions and coral bleaching
- An understanding of the weather conditions that can lead to bleaching

Background

The number of regions reporting mass coral bleaching has increased substantially in recent years. The implications of mass bleaching received global attention in 1997–98, when increased sea surface temperatures associated with El Niño resulted in extensive bleaching of the world's reefs. Prior to this event, coral bleaching was often considered a local problem—someone else's problem—resulting from localized stresses. The event of 1997–98 distinguished mass coral bleaching from localized events by the global extent of its impacts across reefs and reef regions of different condition, composition, and geography. It is attributed to causing mass mortalities of corals to many reef regions, in total 'destroying' an estimated 16 per cent of the world's reefs. This event fuelled scientific curiosity about the causes of mass bleaching events and the implications of these events for future coral reef condition.

Using satellite data over the last 20 years, warming in most tropical areas is easily seen. Unfortunately, these warming trends are expected to continue into the future. Comparisons of expected sea temperature increases with bleaching thresholds suggest that the frequency and severity of mass bleaching events will increase, as the temperature is likely to rise faster than coral reef ecosystems can to adjust. This implies that, should tropical seas continue to warm, coral reef ecosystems are likely to undergo significant changes. These changes include losses to biological diversity and coral cover as well as economic losses to the fisheries and tourism sectors.

Sea temperature is the most reliable predictor of the occurrence and severity of large-scale coral bleaching events. An understanding of the factors that influence sea temperature can help managers predict the risk and severity of a bleaching event. Reef managers may get a very useful indication of whether their region is likely to experience increased heating in coming months based on climate predictions. Longer-term predictions, such as seasonal weather forecasts, can be used to assess the probability of weather conditions that contribute to increasing sea temperatures occurring over timescales of weeks to months. Shorter-term predictions, such as weekly weather forecasts, indicate whether sea temperatures will increase or decrease in coming days and weeks.

Our understanding of mass bleaching suggests that the future condition of coral reefs will be largely influenced by two factors: (1) the rate and extent of sea temperature increases; and (2) the resilience of coral reef ecosystems. The rate and extent of warming will determine the window of opportunity for reefs to adjust through acclimatization, adaptation, and other ecological shifts. For example, fewer and less intense temperature anomalies will reduce the frequency and severity of bleaching events, and slower rates of warming will allow more time for reefs to recover between events that do occur. These relationships mean that the effectiveness of broader efforts to address the rate and extent of warming will have significant implications for local management initiatives. However, such efforts are largely a matter for national and international policy. The focus of this workshop is to consider strategies local coral reef managers can implement to reduce the impacts of mass bleaching events and to restore and maintain the natural resilience of coral reefs to climate change.

Worksheet or Activity

<u>Discussion</u>: Have you witnessed mass bleaching on the reefs in your region?
What were the long terms impacts/recovery in your area?

On-the-Web

Encyclopedia of Earth article on corals and climate change
http://www.eoearth.org/article/Coral_reefs_and_climate_change

Publications and References

Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi and M.E. Hatziolos. 2007. Coral reefs under rapid climate change and ocean acidification. *Science* 318(5857): 1737-1742.

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http://www.coris.noaa.gov/activities/reef_managers_guide/welcome.html

Wilkinson, C., Souter, D. 2008. *Status of Caribbean coral reefs after bleaching and hurricanes in 2005*. Global Coral Reef Monitoring Network, and Reef and Rainforest

Research Centre, Townsville, 152 p.
http://www.coris.noaa.gov/activities/caribbean_rpt/

Slides

Section 3: Delving Deeper into Bleaching Physiology

Learning Objectives

By the end of this module you will have:

- A deeper understanding of the mechanisms that cause coral bleaching
- A background in how light and temperature combine to cause bleaching
- An understanding of how this knowledge can help predict when and where bleaching may occur.

Background

It is often stated that high water temperatures "cause" coral bleaching. That is not strictly true, when you look more closely at the mechanisms within the coral itself.

It's important to remember that corals host symbiotic algae within their cells, called zooxanthellae. These algal cells photosynthesize just like any plant, and the compounds they produce are a crucial energy source for the coral animals. Within the zooxanthellae there is a complex chemical "machinery" that carries out photosynthesis—pigments that absorb light energy from the sun, and a series of proteins and enzymes that convert the solar energy into sugars/carbohydrates that the plant (and its coral host) can use. During the highest-light periods of even a normal day, the system will be overwhelmed with too much solar energy coming in through the pigments. This excess energy is turned into oxygen free radicals, dangerous compounds that damage the photosynthesis machinery and other crucial parts of the cell. The zooxanthellae have another complex system whose job it is to repair this normal light damage. On normal days, all of the damage from excess light can be repaired.

Unfortunately, stressfully warm temperatures will disrupt the balance of damage and repair. The exact mechanism is not yet known, but the overall result is that the zooxanthellae cannot fully repair the daily light damage from the oxygen free radicals. If these conditions continue over several days or weeks, serious consequences will result. The coral can digest or expel the harmful zooxanthellae, so that they will not be further damaged. Since most of the color of a coral colony comes from the zooxanthellae, the coral will then appear pale or white ("bleached").

The worst-case scenario is that the stressful conditions are so severe and long-lasting that the coral colony dies. Without its main food source, the coral may starve to death. The oxygen free radicals from the zooxanthellae and the stress from expelling the symbiotic cells may damage the coral's tissues enough to cause it to die. However, if the stressful light and temperature conditions abate, the coral will be able to recover. The animal will repopulate its tissues with zooxanthellae cells, either from the water column or from reproduction of the few algae cells that remain in the coral tissue. Even if the bleaching doesn't kill the coral, there are long-term consequences from the stress of a bleaching event: drastically slowed growth rate, failure to reproduce that year, and higher susceptibility to coral disease infections.

It is clear that bleaching is caused by a combination of strong sunlight and warm temperatures. Clear skies, low wind, neap tides, and reduced sediment can quickly lead to very high light conditions for the corals. Many of those same factors also cause warming at the ocean surface, of course, which sets up the ideal conditions for coral bleaching.

Publications and References

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Slides

Section 4: Ocean Acidification

Learning Objectives

By the end of this module you will have:

- An understanding of the chemistry behind ocean acidification
- Current scientific knowledge on what the future will bring
- Background on how acidification affects coral reefs

Background

The global oceans are the largest natural reservoir for the excess CO_2 in the atmosphere, absorbing approximately one-third of the CO_2 from human activities each year. As a result, dissolved CO_2 in the surface ocean will likely double over its pre-industrial value by the middle of this century, representing perhaps the most dramatic change in ocean chemistry in over 20 million years.

As CO_2 reacts with seawater it forms carbonic acid, causing a reduction in pH. Seawater is naturally buffered against these pH changes, but the buffering process consumes carbonate ions. Carbonate ion is an essential ingredient in the creation of calcium carbonate ($CaCO_3$) shells and skeletons produced by many marine organisms.

Reef-building corals construct intricate three-dimensional frameworks by calcification (biological precipitation of $CaCO_3$). In order for the reef to grow over time, corals must produce $CaCO_3$ faster than the natural reef removal processes (dissolution, storm export, and bioerosion). Studies of $CaCO_3$ budgets on coral reefs suggest that these building and erosion processes are nearly balanced at most modern reefs, and net reef accretion is small. Many experiments show a reduced rate of calcification as a consequence of ocean acidification. Laboratory studies have examined the effects on many types of corals and coralline algae, revealing a range of responses from a 3% to 60% decline in calcification rate for a doubling of atmospheric CO_2. Recent field studies have also shown declines in coral calcification rates at the Great Barrier Reef, the Arabian Gulf, and Bermuda. These slower growth rates are probably caused, at least in part, by ocean acidification. Thus, a primary threat of ocean acidification is the potential to compromise the ability for reefs to maintain a positive net accretion, thereby resulting in the loss of habitat and coastal protection. This effect is particularly critical because of sea level rise.

Recent work has also shown secondary effects that suggest there is still a lot to learn about how acidification affects coral reefs. A recent lab study shows that lower pH increases a coral's susceptibility to bleaching. Other potential effects include a reduced capacity to tolerate ultraviolet radiation, and increased bioerosion rates.

On-the-Web

Encyclopedia of Earth article:
http://www.eoearth.org/article/Ocean_acidification

Tutorial on OA and coral reefs, from NOAA Coral Reef Watch:
http://coralreefwatch.noaa.gov/satellite/oa/description/oaps_intro_oa.html

Wikipedia entry:
http://en.wikipedia.org/wiki/Ocean_acidification

Scientific information from a global network of researchers:
http://ocean-acidification.net/

Publications and References

Feely R. A., C. L. Sabine, K. Lee, W. Berelson, J. Kleypas, V. J. Fabry, and F. J. Millero. 2004. Impact of anthropogenic CO_2 on the $CaCO_3$ system in the oceans. *Science* 305: 362-366.

Langdon C. and M. J. Atkinson. 2005. Effect of elevated pCO_2 on photosynthesis and calcification of corals and interactions with seasonal change in temperature/irradiance and nutrient enrichment. *Journal of Geophysical Research* 110 (C09S07).

Sabine C. L., R. A. Feely, et al. 2004. The oceanic sink for anthropogenic CO_2. *Science* 305: 367-371.

Slides

Section 5: Global Climate Change and Coral Disease

Learning Objectives

By the end of this module you will have:

- An understanding of hypotheses regarding the increase in disease prevalence worldwide
- An update on current scientific knowledge on coral diseases
- A background on the emerging connection between climate and coral disease
- An understanding of the challenges to managing coral diseases
- A grounding in field assessment of diseases and other known impacts to corals

Background

Disease is a part of all natural systems. However, when a disease increases in spatial or temporal extent or in its capacity to cause mortality, it can become problematic, necessitating active management. Disease of corals and other reef animals is an emerging issue in marine science and management. Because corals provide the living and self-repairing foundation for reef communities, diseases that cause significant mortality to the primary reef building species are of major concern. This concern is based on evidence that diseases are apparently having greater impacts than before, and at a time when reefs are subjected to increasing threats despite global management efforts. This increase is thought to be brought about by a number of drivers, several of which have an anthropogenic link: 1) degradation of nearshore water quality that stresses benthic organisms and may lower their immunodefense capabilities, or expose them to elevated concentrations of pathogens (e.g., white pox disease of *Acropora palmata* in the Caribbean, caused by a sewage-associated bacterium *Serratia marcescens*); 2) increases in species introductions from shipping and the aquarium trade; 3) extension of the geographic range of pathogenic or parasitic species as a result of warming coastal water (e.g., *Perkinsus marinus***,** the protist that causes the disease "dermo" in oysters); 4) introduction of novel pathogens to naïve hosts (e.g., *Aspergillus sydowii,* a soil fungus that causes aspergillosis in Caribbean sea fans); and 5) a change in the virulence or infectiousness of a pathogen as a result of a change in its environment (e.g., *A. sydowii* becomes more virulent in slightly warmer water).

It would be helpful to understand how certain key concepts are currently used and defined. As managers, understanding these key concepts will contribute greatly to creating a global body of reef workers who are all "speaking the same language".

Disease – any impairment that interferes with normal function.
Infectious disease – disease caused by a transmissible agent, such as a bacterium or virus.

Non-infectious disease – disease caused by a non-infectious agent such as a toxin, congenital defect, or environmental stress.

Pathogen – any disease-producing agent; usually a microorganism such as a bacterium, virus or protist.

Outbreak – occurrence of disease at a rate above what is expected in a given population.

Prevalence – the number of disease cases among individuals in a population or area at a given point in time.

Incidence – a change in the number of disease cases within a population or area between two points in time.

Because the science of coral disease is very new, limited empirical evidence exists for a link with climate change. However, several recent key studies have reported compelling associations between elevated sea surface temperature and increased prevalence of white syndrome, bacterial bleaching and black band disease in the Indo-Pacific. In laboratory experiments, black band disease progressed faster within a sick coral, and was transmitted more rapidly between corals, in warmer water. Warmer temperatures have been demonstrated to increase the virulence of the bacterium *Vibrio shiloi* which causes bleaching in *Pocillopora damicornis*. In the Caribbean, disease outbreaks, particularly yellow band disease, have been observed to follow major bleaching episodes, killing corals that survive and apparently recover from bleaching. Extensive work with aspergillosis in sea fans has shown that the host gorgonian (*Ventalina* spp.) has reduced defensive chemistry, while the fungal pathogen (*Aspergillus sydowii*) shows increased virulence, at warmer temperatures. These lines of evidence suggest that disease impacts are likely to increase with rising ocean surface temperatures. However, other consequences of climate change such as rising sea level, which may increase the depth at which many coral communities exist, and ocean acidification, which may have impacts on coral health other than calcification rates, remain unstudied at present.

Coral disease is, therefore, both a new source of coral mortality and reef decline, and a consequence of reef degradation from other stressors. As a developing science, it is challenged by the rather urgent need for management tools which currently do not exist, or have not been adequately tested. In other words, we must, as managers and scientists, develop and test management tools for diseases with inadequate scientific knowledge of how these diseases are operating. We know much about human disease, less about disease in domesticated vertebrate animals and cultured plants, still less about diseases of wildlife, and almost nothing, in comparison, of diseases in lower invertebrates. Our management strategies of diseases for humans and domesticated animals and plants--culling, quarantine, vaccination, and education--are difficult or impossible to apply to a coral reef, with the exception of education. But, whom do we educate and what do we communicate? How do we manage the spread of disease and minimize mortality? Current thinking is that the best proactive management tool for coral disease may simply be to improve and protect water quality and ecosystem function to facilitate the coral’s natural immunodefense mechanisms and optimize resilience. At present, this is chiefly accomplished via establishing and enhancing Marine Protected Areas (MPAs). A growing body of evidence is pointing to a number of ancillary benefits of MPA establishment aside from fishery protection and coral health is one such benefit. However, additional tools will undoubtedly be needed, particularly in cases of disease outbreaks where active response may be needed to mitigate impacts and promote recovery.

Worksheet or Activity

Discussion: What coral diseases and other impacts to coral have you seen in your region? Are there any signs that you have not seen before (i.e., potential new or emerging diseases)? Are there signs that appear to be more common or frequent than before? Do you notice any signs of disease that occur more or less frequently in different seasons (i.e., rainy vs. dry; cool vs. warm)?

On-the-Web

Intergovernmental Panel on Climate Change
http://www.ipcc.ch/

NOAA “Frequently Asked Questions” on climate change
http://www.ncdc.noaa.gov/oa/climate/globalwarming.html

Coral Reef Targeted Research and Capacity Building for Management
http://www.gefcoral.org

Publications and References

Bruckner AW (2002) Priorities for Effective Management of Coral Diseases. National Oceanic and Atmospheric Administration. Washington, D.C. 54 pp.

Sutherland KP, Porter JW, Torres C (2004) Disease and immunity in Caribbean and Indo-Pacific zooxanthellate corals. Marine Ecology Progress Series 266:273-302

Raymundo LJ, Couch CS, Harvell CD (2008) Coral Disease Handbook: Guidelines for Assessment, Monitoring and Management.

Module 5: Early Warning Systems

Section 1: Tools to Predict Mass Bleaching

Learning Objectives

By the end of this lesson you will have:

- An understanding of the importance of early warning systems in predicting mass bleaching events.
- A basic understanding of remote sensing and how satellites measure sea surface temperature (SST).
- The ability to access and interpret SST and SST anomaly data on the NOAA website.
- A knowledge of the methodology Coral Reef Watch uses to predict bleaching from satellite measurements of sea surface temperature.
- A suite of tools that will warn managers when their reefs might be at risk from elevated temperatures.

Background

A manager's response to bleaching has three major components: An early warning system for predicting and identifying mass bleaching events, an assessment and monitoring program to measure the impacts of bleaching, and a communication program. An early warning system provides information for managers to communicate to the media, government and stakeholders about the likelihood of bleaching events. Early warning systems also allow managers to identify the location and potential extent and severity of bleaching events to be able to mobilize an assessment and monitoring response.

Prediction of bleaching serves three main purposes: It allows managers to predict whether a bleaching event is likely to occur and how severe the impacts might be, it helps managers prepare for an impending bleaching event in order to monitor and manage impacts, and it also helps mangers identify where the greatest impact is likely to be and therefore where to focus management, assessment and monitoring efforts. Mass coral bleaching is preceded by environmental conditions that can be tracked to provide managers with an effective early warning system for bleaching events.

An understanding of the factors that influence sea temperature has the potential to enable managers to predict the probability of occurrence and severity of a bleaching event. In theory, the relationship between climate patterns, seawater heating, and mass bleaching should provide a mechanism for such predictions. In particular, the weather patterns associated with phenomena such as the El Niño Southern Oscillation or the Pacific Decadal Oscillation can be associated with regional and local warming sea temperatures. Weather patterns also provide a useful indication of whether bleaching risk is increasing or decreasing. Longer-term predictions, such as seasonal forecasts, can be used to assess the probability of weather conditions that contribute to increasing sea temperatures occurring over timescales of weeks to months. For example, seasonal outlooks for the hot season that predict above-average air temperatures and decreased storm activity indicate that there is an increased probability of conditions that can lead to stressful sea temperatures.

Shorter-term predictions, such as weekly weather forecasts, indicate whether sea temperatures will increase or decrease in coming days and weeks. The risk of mass bleaching is higher when forecasts are for high air temperatures and extended periods of clear skies, low wind and neap tides. In contrast, forecasts for stormy conditions with cooler air temperatures, high cloud cover and strong winds indicate that sea temperatures may stabilize or decrease over the coming week. Once atmospheric conditions suggest the development of unusually warm conditions, measurements of sea temperatures provide a more direct indication of the potential for mass coral bleaching. Temperature stress can be monitored using satellite imagery and in-water instruments.

Sea surface temperature (SST) is known to be variable in both space and time. Fortunately, we can measure this temperature globally and in near-real-time, from the polar-orbiting satellites that NOAA deploys. This technique is known as remote sensing.

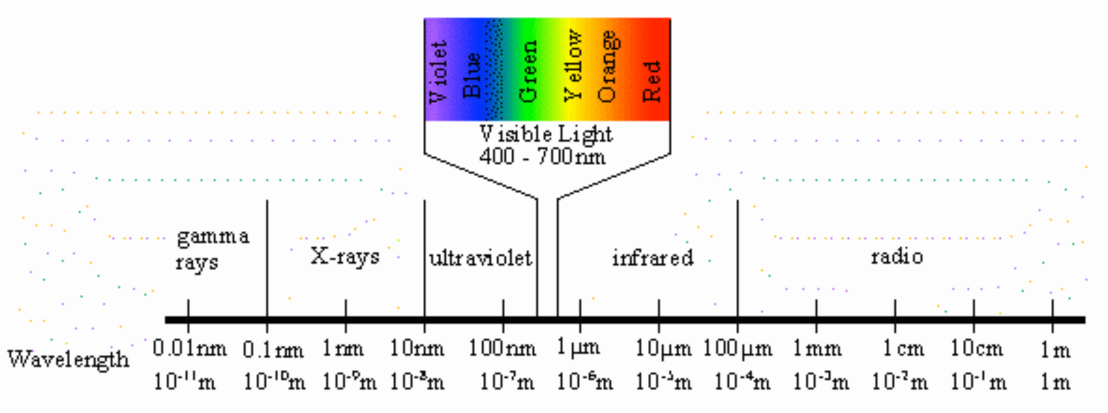
What is remote sensing?

Basically, remote sensing means measuring some property of an object without actually touching it. Usually, we add some interpretation to this measurement to draw conclusions about the object we are sensing.

For example, our eyes and ears are remote sensing instruments, and in fact humans are all skilled remote sensors. Let’s take an example. How can you tell if the burner on an electric stove is hot, without touching the surface and burning your hand? There are actually two ways that you use remote sensing to tell whether the burner is cool or hot. The first way is to look at the color of the burner. If it is red, you can interpret that color to mean that the burner is very hot. But if the color is black, the stove still may be quite hot. What other sense can you use to detect if the burner is warm?

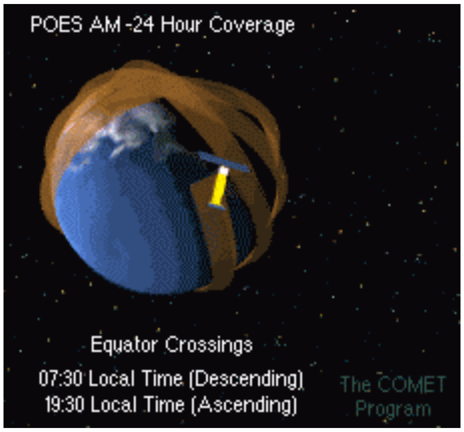
Answer: If you put your hand close to the burner, you can feel the heat without touching the surface. Your skin is actually sensing the infrared radiation from the stove. As you will see, this is similar to the way satellites measure the temperature of the ocean’s surface.

Remote sensing uses sensors that measure parts of the electromagnetic spectrum. This "spectrum" is a way of talking about natural energy: from x-rays and ultra-violet light (UV), through visible light, to infrared (IR) and microwaves. At the right are high-energy waves like gamma rays, which pass right through physical matter. In the center is a narrow band of energy that our eyes are tuned to detect—visible light, from higher-energy blue light to the lower-energy red. The next section of this spectrum is called infrared. This is energy that we can feel as heat, like what comes off the hot burner on your stove. All the way at the lower (left) end are radio waves, which have low energy and long wavelengths. Many of these forms of energy are used in remote sensing.



Satellite remote sensing

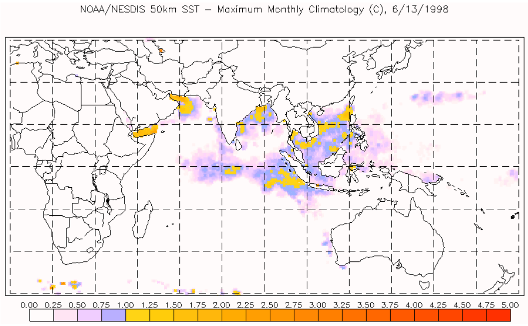
NOAA operates two different types of satellites that carry remote sensing instruments. Geostationary satellites stay in the same position relative to Earth, so they can take frequent measurements of an area throughout the day and night. However, each satellite can only see a fraction of the Earth's surface. Because coral reefs are located all around the world, the Coral Reef Watch program uses NOAA's polar-orbiting satellites. Although they can only measure a given area once or twice a day, they have the advantage of getting measurements around the entire planet.



There are only 4 properties of the ocean that a satellite can directly measure:

- How far away is the water surface?
- How rough is the surface?
- What color is the water?
- What is the temperature of the water?

It is this last property that can be directly used in monitoring for bleaching conditions.



The Coral Reef Watch program has customized NOAA's satellite SST measurements into trusted data products that highlight areas that are currently at risk for coral bleaching. HotSpot maps (Strong et al. 1997) show SSTs that are currently above the monthly mean temperature we expect to see in the hottest month. The mapped HotSpots are updated twice each week, and have proven to be a very reliable indicator of current temperature stress in coral reef areas. However, we also know that the duration of the heat stress is also important in predicting the severity of coral bleaching. Coral Reef Watch therefore also produce Degree Heating Week (DHW) maps that combine the HotSpot intensity of the temperature anomaly with the duration of exposure, providing a composite picture of cumulative thermal stress over the last 12 weeks. One DHW is equivalent to one week of SST at 1 °C greater than the expected summertime maximum. Two DHWs are equivalent to two weeks at 1 °C above the expected maximum or one week of 2 °C above the expected maximum. At DHWs over 4, the Coral Reef Watch program issues a Coral Bleaching Alert that mass bleaching is likely to be occurring.

Worksheet or Activity

Activity: "You Make the Call"

Purpose: The purpose of the "You Make the Call" exercise is to integrate information from many different sources to determine if the reef you are managing is at risk for bleaching. The exercise spans three weeks, and participants will consider how changing weather, sea surface temperature, and local conditions might change the threat of bleaching.

Instructions: Instructor will divide participants up into four groups based on their location in the room. Your group will receive a piece of paper with a type of reef and basic information about the reef. The information will include:

- Reef type
- Tidal range
- Important information about adjacent landscape features, uses, etc.
- Current Conditions

- Recent Weather
- Satellite Bleaching Alert Status
- Bleaching Observations
- Other Relevant Events

Based on current conditions for this first week including recent weather, satellite bleaching alert status, bleaching observations and other events you will be asked to determine how great a threat your reef is for widespread coral bleaching. Once the threat level is determined for week 1, updated information for week 2 and then week 3 will be passed out. Based on changes in weather, satellite bleaching alert status, etc. participants will be asked to revise their threat level over time.

On-the-Web

NOAA Coral Reef Watch:

Homepage: http://coralreefwatch.noaa.gov/satellite

Tutorial on our data products:
http://coralreefwatch.noaa.gov/satellite/education/tutorial/welcome.html

Sign up for free Satellite Bleaching Alert e-mails: http://coralreefwatch-satops.noaa.gov/SBA.html

Florida Keys BleachWatch program:
http://isurus.mote.org/Keys/bleaching.phtml

Florida Keys Current Conditions Reports:
http://isurus.mote.org/Keys/current_conditions.phtml

Great Barrier Reef Current Conditions Reports:
http://www.gbrmpa.gov.au/corp_site/info_services/science/climate_change/management_responses/current_condition_reports/

GBRMPA Bleachwatch Program:
http://www.gbrmpa.gov.au/corp_site/info_services/science/climate_change/management_responses/bleach_watch2.html

ReefTemp: (Australian high-resolution satellite bleaching tools)
http://www.cmar.csiro.au/remotesensing/gbrmpa/ReefTemp.htm

Mesoamerican Coral Reef Watch Program:

http://mesoamericanreefwatch.net/en/bleachwatch/bleachwatch.php

Other key links:
NOAA Coral Reef Conservation Program, with info on all of NOAA's coral reef activities:
http://www.coralreef.noaa.gov/

Submit a bleaching report to ReefBase:
http://www.reefbase.org/contribute/bleachingreport.aspx

Publications and References

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Coles, S. L. and B. E. Brown (2003). Coral bleaching - capacity for acclimatization and adaptation. *Adv. Mar. Biol.* 46:183-223.

Glynn, P.W. (1993). Coral-reef bleaching – Ecological perspectives. *Coral Reefs* 12: 1-17.

Glynn PW, D'Croz L (1990) Experimental evidence for high temperature stress as the cause of El Niño- coincident coral mortality. Coral Reefs 8: 181-191.

Goreau, T. J. and R. Hayes, 1994. Coral Bleaching and Ocean "Hot Spots." *Ambio*, 23:176-180.

Hoegh-Guldberg, O. (1999). Coral bleaching, Climate Change and the Future of the World's Coral Reefs. *Mar. Freshwater Res.* 50:839-866.

Hoegh-Guldberg, Fine, Skirving, Johnstone, Dove, and Strong*,* Coral bleaching following wintry weather, *Limnol. & Oceanogr., 50(1), 265–271,* 2005.

Liu, G., A.E. Strong, and W. Skirving. 2003. Remote sensing of sea surface temperature during 2002 Barrier Reef coral bleaching. *EOS,* 84(15), 137-144.

IPCC (2001). *Climate Change 2001: The Scientific Basis.* Published for the Intergovernmental Panel on Climate Change by the Cambridge University Press, Cambridge, United Kingdom.

Strong, A. E., C. B. Barrientos, C. Duda, and J. Sapper (1997). Improved satellite techniques for monitoring coral reef bleaching. *Proc 8th International Coral Reef Symposium*, Panama City, Panama, p 1495-1498.

Strong, A. E., F. Arzayus, W. Skirving, and S. F. Heron. Identifying coral bleaching remotely via Coral Reef Watch – improved integration and implications for climate change. Chapter 9 in *Coral Reefs and Climate Change: Science and Management*, J. T. Phinney, O. Hoegh-Guldberg, J. Kleypas, W. Skirving, and A. E. Strong (Co-Eds), American Geophysical Union, 2006.

Slides

Section 2 Community-based Monitoring

Learning Objectives

By the end of this lesson you will:

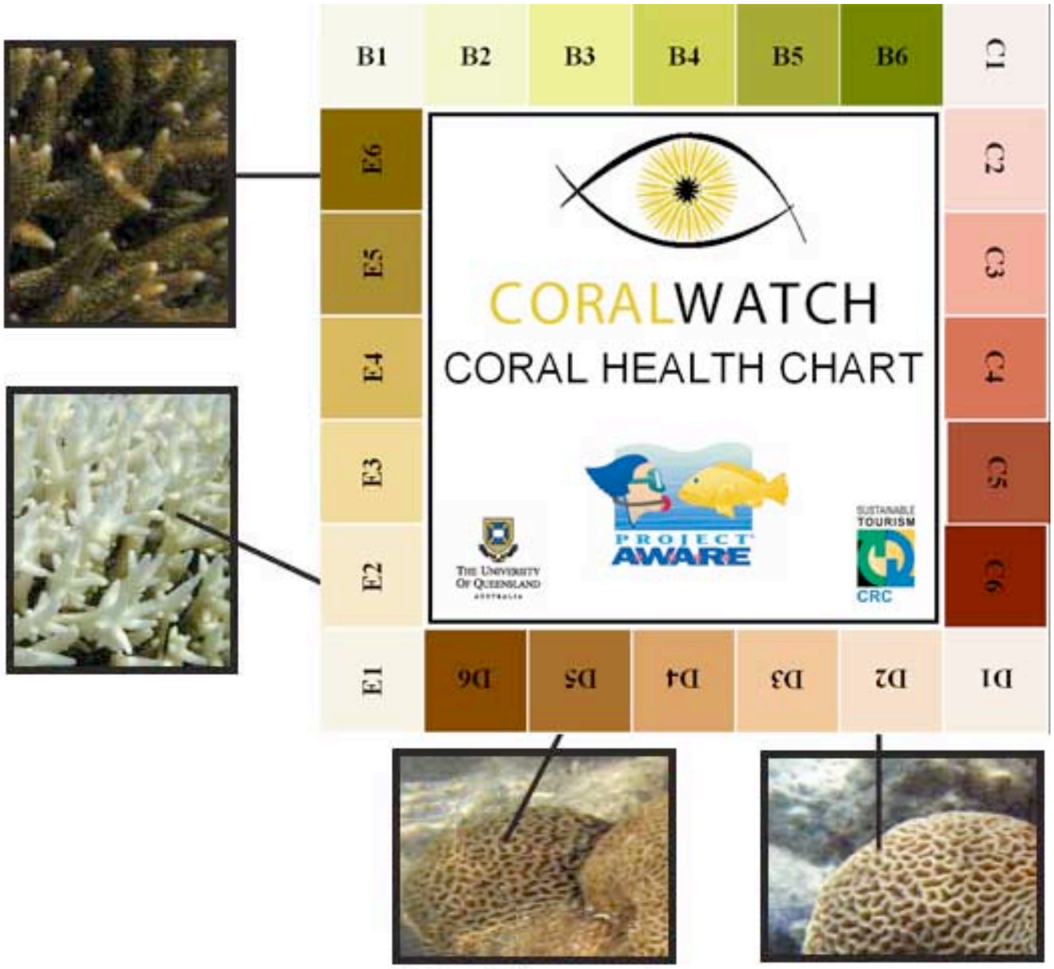
- Understand the role of community or citizen monitoring in an Early Warning System and as a component of a management response to a mass coral bleaching event, disease outbreak, etc.
- Understand the components of community-based monitoring and its strengths and weaknesses.
- See examples of a number of community-based monitoring programs.
- Understand the role of ReefBase.

Background

One the first community-based monitoring programs was established on the Great Barrier Reef by the University of Queensland. The following information was taken from their website (http://www.coralwatch.org/ProjectDetails/default.aspx).

Current attempts to monitor coral bleaching often involve costly satellite-born technologies, are restricted to locations researcher are working in and often require sampling of live tissue for physiological analysis. Our coral reef monitoring approach using color charts is the first attempt to provide useful data on a relatively large scale with the help of an inexpensive, 'user friendly' and non-invasive device. At the University of Queensland, Australia we have developed a method of coral health monitoring which uses simple color charts, like paint color matching charts. This is a result of the unusual union between world leading vision and color experts at VTHRC (Vision, Touch and Hearing Research Centre) and world leading coral experts at CMS (Centre for Marine Studies). The color charts can be used by anyone, scientists, school children, tourists and politicians. Perhaps most importantly, the opportunity for everyone to participate in a global reef-monitoring project removes the sense of hopelessness felt by many in the face of outcomes predicted from global warming. With this monitoring program we also aim to educate the public about coral bleaching and its devastating effect on coral reefs.

This is how it works: The color charts are based on the actual colors of bleached and healthy corals. Each color square corresponds to a concentration of symbionts contained in the coral tissue. The concentration of symbionts is directly linked to the health of the coral. All you have to do is match the color of the coral with one of the colors in the coral health monitoring chart. You then record the matching color codes, along with coral type (species if possible), on the website data sheet (***www.coralwatch.org***).



Staghorn coral after recovery in May 2002

Staghorn coral during bleaching in March 2002

Brain coral after recovery in May 2002

Brain coral after recovery in May 2002

Why we need your help: Little is known about trends of coral bleaching on a global scale, though as these bleaching episodes increase in frequency we are learning more. Currently coral health monitoring mainly occurs around a few reefs that are regularly visited by scientists. There are many questions that will have to be answered in order to try and save the reefs. This is where you can help! If many people around the world, like you, participate in the monitoring program we will be able to answer questions such as:

1. Large and small-scale pattern of coral bleaching: Based on water temperature measurements and knowledge of currents, it is possible to predict which areas will be affected by bleaching. We hope to answer several questions within this. Do all reefs bleach during every El Niño event, or are there some reefs/zones of reef that never bleach? Does the same reef bleach every time?
2. Duration and severity of coral bleaching: How long are different reefs affected by bleaching events? How severely are different reefs around the world affected? Is the severity and duration dependent on whether or not a reef has bleached before? Does the overall health of the reef get worse from one bleaching event to another?

3. Large and small scale pattern of recovery: To date most research has concentrated on the onset of bleaching rather than recovery. With your help it will be possible to measure recovery - how long after the drop in water temperature do different reefs recover? How long does recovery take? Is it variable between different reefs and different coral types?

With your help it will be possible to monitor coral health throughout the year, not just during bleaching events. It is important to measure the small natural fluctuations in the coloration of healthy corals, which do happen seasonally, so that we can immediately identify if there is a color change outside the normal range. In this way it will be possible to find out if there are other factors that may influence coral health throughout the year. (Source http://www.coralwatch.org)

Using this sentinel community-based monitoring program as a template, many other such programs have been developed around the world. We will discuss some of those projects as well as their many levels of usefulness to scientists and managers.

Worksheet or Activity

Activity: Take your Coral Watch kit out to the reef and practice being part of a citizen monitoring program.

Activity: Explore the ReefBase website on your own (www.reefbase.org).

Worksheet: “Monitoring and Reporting Bleaching Conditions” in your Bleaching Response Plan

MONITORING AND REPORTING BLEACHING CONDITIONS

The activities in the right-hand column are examples of activities related to monitoring and reporting bleachin
modify these as is appropriate for your site. It is important to identify these activities and who will be responsib
Choose a back-up who is not likely to be on travel or vacation at the same time as the primary person. Deter
activities. The Great Barrier Reef Marine Park Authority table of activities is provided on the back of this shee

Frequency (e.g. weekly)	Timing (e.g. every Monday)	Person Responsible (also provide back-up)	Activity (modify and fill in other activities as needed)
Routine tasks:			
			Check the NOAA Seasonal Bleaching Outlook
			Check NOAA HotSpot & DHW maps on web
			Receive and review Coral Reef Watch Satellite Bleaching Aler
			Review weekly weather summary (e.g., air temp, cloud cover
			Review Coral Reef Watch reports and update maps
			Make use of traditional Hawaiian seasonal prediction tools
			Brief senior management team on weather and heating condit
			(optional: if you publish bleaching conditions on your website and coral conditions and draft bleaching risk current condition recent images. Announce web update and send brief report.
			Monitor extent of bleaching using existing information channel
			Advise senior management if dramatic worsening of condition
			Others:
Responsive tasks:			
			Actively solicit confirmatory bleaching reports from reliable sou monitoring participants, field scientists, tourist/dive operators,
			Alert relevant project coordinators and managers
			Brief senior management
			Brief elected officials
			Prepare media position, draft statement and consult with medi
			Brief all staff, stakeholders and collaborators
			Release media statement
			Actively promote and solicit submissions to online bleaching r spatial coverage
			Implement Bleaching Assessment and Monitoring component
			Others:

MONITORING AND REPORTING BLEACHING CONDITIONS

EXAMPLE: From GBRMPA Bleaching Response Plan

Frequency	Timing	Person Responsible (back-up)	Activity
weekly	Monday		Check GBRMPA ReefTemp and NOAA HotSpot maps on web
			Receive updated Great Barrier Reef sea temperature graphs from AIMS
			Review weekly weather summary, for example air temp, cloud cover and wind from Bureau of Meteorology
			Review BleachWatch (including BleachWatch Aerial) reports and update maps
			Print out ReefTemp and NOAA HotSpot maps for GBRMPA Climate Change Group Director to brief senior management team
Weekly/ fortnightly	Tuesday		Summarise weather, sea and coral conditions and draft bleaching risk current conditions report for website. Include recent images.
Weekly/ fortnightly	Wednesday		Have updated current conditions report reviewed, approved and published on external web
			Announce web update and send brief report
Weekly/ fortnightly	Constant		Monitor extent of bleaching using existing information channels and evaluate for trends (ie change in bleaching extent)
			Advise GBRMPA senior management team and the Minister for the Environment, Heritage and the Arts if dramatic worsening of conditions is evident
Event-based	High bleaching risk		Actively solicit confirmatory bleaching reports from reliable sources, including BleachWatch participants, Day-to-Day Management field officers, AIMS, other researchers, etc.
			Alert relevant project coordinators and managers
			Brief GBRMPA senior management team
Event-based	Moderate bleaching event detected		Brief GBRMPA executive and the Minister for the Environment, Heritage and the Arts
			Prepare media position, draft statement and consult with GBRMPA media coordinator and executive
			Brief all GBRMPA staff, stakeholders and collaborators
			Release media statement
			Actively promote and solicit submissions to online bleaching reports to provide wide spatial coverage
			Implement Bleaching Assessment and Monitoring component

On-the-Web

Coral Watch (University of Queensland):
www.coralwatch.org

Bleach Watch (Great Barrier Reef Marine Park Authority):
http://www.gbrmpa.gov.au/corp_site/key_issues/climate_change/management_responses/bleach_watch2.html

Eyes on the Reef, Reef Check Hawaii:
http://www.reefcheckhawaii.org/eyesofthereef.htm

Florida Keys Bleach Watch:
http://isurus.mote.org/Keys/bleaching.phtml

MesoAmerican Coral Reef Watch Program:
http://www.marcoralwatch.net/

Slides

Module 3: Principles and Components of Resilience

Section 1: What is Resilience?

Learning Objectives

By the end of this lesson, you will be able to:

- Define *biological resilience* and explain it in clear terms
- Define *social resilience* and explain it in clear terms
- Explain the three components of *social resilience*

Background

Resilience refers to the ability of a system to maintain key functions and processes in the face of stresses or pressures by either resisting or adapting to change. There are two components of resilience: the ability to absorb or resist the impacts of stresses, such as mass bleaching or storms, and the ability to recover quickly from them. Resilience can be applied to both ecological systems as well as social systems. In this training, resilience is used in the context of global climate change; however a resilience-based approach can be integrated into management of any natural system.

Biological Resilience

Coral reef resilience is ultimately about coral reef health. Having a healthy 'immune system' helps coral communities withstand major stress events such as warming seas and recover rapidly from them. Building resilience into reef management means helping to build the immune system, and increasing the likelihood that coral communities will continue to thrive. Resilience can be applied to all marine systems—temperate, tropical, or polar. The general concepts and principles are the same across all areas, yet specific actions need to be adapted for the region or habitat of interest.

Social Resilience

The concept of resilience has also been applied to social systems and how they relate to management of natural resources. Social resilience focuses on the resilience of communities in adapting to and withstanding institutional, environmental and economic changes in their location. Often these changes take the form of policies and regulations that alter long-standing local habits and practices with more resilient communities more likely to comply and sustain change. But most importantly, changes take the form of reduction in supply of goods and services as a result of ecosystem impacts from climate change. Resilience of social systems is often related to three different characteristics:

1. the magnitude of shock the system can absorb and remain stable
2. the degree to which the system is capable of self-organization

3. the degree to which the system can build capacity for learning and adaptation

Although this training does not attempt to address the complexities of socio-ecological resilience, it is important for managers to use holistic strategies that acknowledge the importance of resilience in both the natural resources they manage and the communities that will be affected by management actions.

On-the-Web

The Resilience Alliance: http://www.resalliance.org

Resilience Science Blog: http://rs.resalliance.org

Ecology and Society: http://www.ecologyandsociety.org

Publications and References

Management of Mangrove Communities: **http://data.iucn.org/dbtw-wpd/edocs/2006-041.pdf**

How Resilient is Your Coastal Community: A Guide for Evaluating Coastal Community Resilience to Tsunamis and Other Hazards:
http://apps.develebridge.net/usiotws/13/CoastalCommunityResilience%20Guide.pdf

Folke, C., Carpenter, S.R., and Elmqvist, T. 2002. Resilience and sustainable development: building adaptive capacity in a world of transformations. Ambio 31: 437–40.
http://www.geog.mcgill.ca/faculty/peterson/PDF-myfiles/responseDiv.pdf

Holling, C.S. 1973. Resilience and stability of ecological systems. Institute of Resource Ecology, University of British Columbia, Vancouver, Canada 4: 1-23.
http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.es.04.110173.000245

Nyström, M., and Folke, C. 2001. Spatial resilience of coral reefs. Ecosystems 4: 406–417.

Section 2: Four Principles of Resilience

Learning Objectives

By the end of this lesson, you will be able to:

- Identify and explain the four main principles of resilience
- Describe effective management fundamentals: communication, measuring up, adaptive management, and precautionary approach

Background

Until recently, resilience had never been explicitly defined or listed as a criterion for MPA selection or MPA design, nor had it been factored into large-scale ecoregional planning. Yet the concept of resilience demonstrates that there are positive actions we can take to counter potentially devastating impacts of climate-related bleaching. The Nature Conservancy developed a Resilience Model to help frame resilience in an easily understandable way. This model has evolved over time and continues to be refined. It is important to understand that this is a conceptual model, designed to emphasize the key aspects of managing for resilience, but does not guarantee resilience if all principles are addressed. Every situation is unique and it may not be possible to address each and every principle at a site. The principles of resilience are briefly explained below and in more detail later in the workbook.

Principle 1: **Representation and Replication** (and risk-spreading) can help increase likelihood of reef survival. By ensuring that resilient species and habitats are well represented and replicated throughout an MPA network, coral reef managers can decrease risk of catastrophic events, like bleaching, from destroying entire reef ecosystems.

Representation and replication help spread risk in event of a major lethal or sublethal disturbance. To capture the complete array of biodiversity, MPAs should be selected to represent the full national or regional range of coral reefs, and major reef habitat types (e.g., fore-reef, back reef, reef flat) and should include other functionally linked habitats such as sandy and rocky seabed, seagrass, mangrove, coastal, and riparian areas. If biodiversity of a system is fully represented in multiple examples, the likelihood of losing all of it to an event is substantially decreased. Because this applies to any disturbance, it is a ‘no-regrets’ strategy when designing and delineating protected areas.

Representation is about more than just habitats and species. Representation is about including the diversity of characteristics found in an area. There may be special physical features, latitudinal distributions, or energy regimes that should be considered. Neighboring habitats that are functionally linked to coral reefs by physical and ecological processes—including the transport of nutrients by currents or daily feeding migrations of reef species—are integral to the health and resilience of coral reefs.

Replication of distinct, representative habitats in MPA networks helps ensure that refugia for each community type remain after a catastrophic die-off. That will help maintain viable sources of larvae to seed the recovery of susceptible areas in times of stress. The suggested absolute minimum number of replicates of a particular habitat type is **three**; however, including more replicates should be a priority whenever possible.

Principle 2: **Critical Areas** are vital to survival and sustainability of marine habitats. These areas may provide secure and essential sources of larvae to enhance replenishment and recovery of reefs damaged by bleaching, hurricanes or other events. They also include high-priority conservation targets, such as fish spawning aggregations and nursery habitats.

Critical areas are vital to the survival and sustainability of marine habitats. These areas may provide secure and essential sources of larvae to enhance the replenishment and recovery of reefs damaged by bleaching, hurricanes or other events. They include high-priority conservation targets, such as nesting areas, nursery habitats, migration routes, or refuges from large-scale disturbances.

When identifying areas for protection and focusing management activities, it is important to include critical areas in the design of the MPA (or network) to promote healthy ecological systems capable of responding to, and sustaining, different kinds of stress. Being sure to account for ecological linkages and processes as well as including resistant and resilient communities in your management approach is fundamental in addressing this principle.

Principle 3: Connectivity influences the design of marine protected area networks. Preserving connectivity among reefs and their associated habitats ensures replenishment of coral communities and fish stocks from nearby healthy reefs, and may enhance recovery.

Understanding and maintaining the ecological patterns of connectivity is an important component of coral reef management. Connectivity describes the extent to which populations in different parts of a species' range are linked through the exchange of eggs, larval recruits, propagules, juveniles, or adults. Imagine what might happen if a particular reef is strictly protected while its neighbor reef, historically an important source for larvae recruits, is zoned as a high impact tourism area. The likelihood of a continued relationship (supplying coral recruits) is certainly reduced.

Recent advances in science and technology are providing answers to the connectivity questions, indicating that a substantial amount of self-recruitment occurs within reef communities and that there is great variation in dispersal distances. Models are also being used to predict the connectivity of adjacent or distant reefs. Because most locations don't have the benefit of focused scientific research to answer these questions, some rules of thumb for connectivity have been developed (For rules of thumb, see Module 3).

Principle 4: Effective Management is essential to meeting goals and objectives of an MPA, and ultimately keeping reefs vibrant and healthy. Reducing threats is the foundation for successful conservation and the core of our resilience-based strategies. Measuring effective management provides the foundation for adaptive management. Investments in human capacity and long-term financing are also crucial to sustaining effective management for the future.

Effective management is the most important principle in the Reef Resilience Model. Effective management refers to the daily activities required of managers, as well as larger community-based efforts to address such problems as local pollution, and poorly planned coastal development, and destructive fishing practices. All of these activities continue to be a priority, in the context of resilience-based management. In the face of global climate change, it is critical for managers to work with stakeholders to reduce and eliminate major threats to coral reef communities that occur locally.

Effective Management Fundamentals

Communication: Communication is often both the reason for success and the reason for failure of management strategies. Focusing on the two-way communication of information between stakeholders and managers is critical to achieving management goals and objectives. Making sure the community is fully aware of the rationale for management activities, as well as the intended outcome, will help gain support for current and future actions.

Measuring Up: In order to manage effectively, a manager must stay informed about changes and progress in the managed area. Understanding the impact certain threats are having, or the response a particular management action is having, helps managers make necessary adjustments, as well as justify management activities based on these trends. There are a variety of resources to help managers evaluate management of their sites, depending on the kind of information and resources available.

Adaptive Management: Once managers have collected information about progress and trends, decisions must be made about current and future strategies. Adjustments in management (e.g., regulations, zoning, or in protected area boundaries) are facilitated by having institutional flexibility incorporated into the management framework. Ensuring that both the community and legislative bodies are prepared for changes in the resource management approach will enable the process of change to occur more efficiently.

Precautionary Approach: Employing a precautionary approach whenever information is lacking is a reasonable way to proceed. The precautionary principle is defined as follows: When an activity raises threats of harm to human health or the environment, precautionary measures should be taken, even if some cause and effect relationships are not fully established scientifically (Wingspread Statement’s Definition, 1998). The precautionary principle suggests that caution be taken in decision-making, but that it does not lead to paralysis until perfect information is available. Designing MPA networks using local knowledge and customary management practices (when possible) can be important elements of a precautionary design, and can be accessed in situations when limited “formal” data have been acquired.

On-the-Web

Reef Resilience Toolkit: http://reefresilience.org/Toolkit_Coral/C1c0_Principles.html

Publications and References

Almany, R.G., Berumen, L.M., Thorrold, R.S., Planes, S., and Jones, P.G. 2007. Local replenishment of coral reef fish populations in a marine reserve. Science 316 (5825): 742–744. (http://www.sciencemag.org/cgi/reprint/316/5825/742.pdf)

Becker, B.J., Levin, L.A., Fodrie, F.J., and McMillan, P.A. 2007. Complex larval connectivity patterns among marine invertebrate populations. PNAS 104 (9): 3267-3272. (http://www.pnas.org/content/104/9/3267.full.pdf+html)

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Holling, C.S. 1973. Resilience and stability of ecological systems. Institute of Resource Ecology, University of British Columbia, Vancouver, Canada 4: 1-23. (http://arjournals.annualreviews.org/doi/abs/10.1146/annurev.es.04.110173.000245)

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Palumbi, R.S. 2004. Marine reserves and ocean neighborhoods: The spatial scale of marine populations and their management. Annual Review of Environment and Resources 29: 31-68.

Section 3: Identifying Resilience

Learning Objectives

At the end of this lesson, you will be able to:

- Identify the three major factors of resilience.
- Explain the two main resilience ‘bottlenecks’ and what factors influence the role they play in reef resilience.
- Explain the genetic and species differences that influence corals’ response to temperature stress.
- Describe physical conditions that may increase resistance to temperature stress.

Background

As managers, it is helpful to have a good sense of what resilience looks like. Resilience is more than being able to recover from a major disturbance, surviving bleaching, or resisting bleaching. For a community to be resilient, it must also be able to continue to thrive, reproduce, and compete for space and resources. For example, coral communities that have experienced bleaching but not mortality may be weakened and less able to thrive, grow, and reproduce in the competitive reef environment

Multiple factors contribute to resilient coral communities, some of them known and others to be discovered. Scientists are working to identify important ecological, biological, and physical factors that managers can evaluate to determine the health or resilience of a coral community. It is important to be able to identify and better understand these factors, so management strategies can be focused on maintaining or restoring communities to these optimal conditions to maximize coral survival after stressful disturbances.

Ecological Factors

The ecological processes that maintain reef function and support thriving reef communities play an important role in maintaining resilience to major disturbances such as coral bleaching. Complex food-web interactions (e.g., herbivory, trophic cascades) reproductive cycles, population connectivity, and coral and fish recruitment are among the ecological processes that scientists have recently been studying in a reef resilience context.

Many questions remain about how, when and where these factors are important. Recently, scientific evidence demonstrates the consistent importance of the presence of top predators and large herbivores as well as the importance of coral and fish recruitment rates and patterns for reef resilience. This section discusses two ecological processes, herbivory and recruitment, that serve as resilience ‘bottlenecks’ in many reef systems and thus should be a focus in reef managers' activities.

Herbivory:

Prohibiting or limiting the take of herbivorous species should be a high priority for reef managers, and is critical for maintaining reef resilience. Recent research has demonstrated the importance of herbivores in facilitating coral recovery following major disturbances such as a bleaching event. Herbivores are known in many ecological systems as key actors regulating both community structure and function.

In the case of coral reefs, herbivores play a critical role in regulating the competitive relationship between macroalgae and corals. Macroalgae and corals compete for space and when herbivores are not present, the faster growing macroalgae often overgrow corals, depriving them of essential sunlight and causing their decline. For example, in the early 1980's Caribbean reefs experienced a sudden shift from coral dominated reefs to reefs with substantial macroalgae populations, following chronic fishing of herbivores and then subsequent die-off of a key herbivore, *Diadema antillarum*.

Managing Herbivory Regimes:

Reef managers should work to maintain a balanced assemblage of coral and algal communities. Once algae have taken over, it is difficult to reverse the trend. When this occurs, management activities should focus on rebuilding and protecting herbivore populations. Following a major disturbance event, herbivores play an important role in inhibiting algal growth, providing coral larvae opportunity to recolonize dead substrate. Recent studies have identified specific types of herbivores (large-bodied parrotfish) that seem to be more important, at least at the regional scale. Any management strategy that reduces algal cover may enhance the recovery of coral and the resilience of the community.

Critically Important herbivores in the Caribbean: *Scarus vetula*, *Sparisoma viride*, and *Sparisoma aurofrenatum* (P. Mumby, pers. comm.)

Recruitment:

Recruitment is the measure of the number of young individuals (e.g., fish and coral larvae, algae propagules) entering the adult population, in other words, it is the supply of new individuals to a population. Recruitment can play a critical role in the resilience of coral populations through the number of individuals and different species that repopulate a reef. Its importance for community dynamics and coral populations varies by species, habitat and reef location. The rates, scales, and spatial structure of dispersal among populations drive population replenishment, and therefore have significant implications for population dynamics, reserve orientation, and resilience of a system. For dispersing larvae, the number of new recruits entering a population is primarily related to five factors: physical oceanographic processes, abundance of larvae, larval behavior, availability of settlement habitat, and ecological factors such as competition and predation.

All of these processes affecting the magnitude of recruitment into a system can influence the spatial patterns of coral reef species communities and assemblages. For coral bleaching, larval recruitment is a particularly critical component of the recovery process. Reefs that have been severely damaged are reliant on the arrival of larvae from corals that have survived the bleaching event elsewhere and their successful settlement, survival and growth.

Biological Factors

Bleaching is a dynamic process and there are few data with which to predict the capacity of corals to withstand climate change. However, several known biological factors of both coral and zooxanthellae influence the degree of resistance or resilience to coral bleaching. Resilience or resistance to bleaching is highly variable, with differences observed among coral colonies of the same species, between colonies of different species, and within individual coral colonies. Different responses of species and individuals to thermal heat stress can be partially attributed to biological factors of individual coral and symbiotic zooxanthellae.

Genetic Differences: Within species, susceptibility to bleaching and mortality can differ, even under the same environmental conditions. These differences between individuals suggest that genetic variation within coral populations can create resilience to increased thermal stress. (See R2 Toolkit for more details)

Species Differences: From a colony perspective, species that are characterized by fine-structured, branching or tabular growth forms, and thin or well-connected tissue, tend to be less resistant to bleaching. Corals that are less resistant to bleaching tend to be those corals that are quick to colonize free space, are fast growing, and often short-lived. Coral species that are more resistant to bleaching can be characterized by massive growth forms, thick or less-integrated tissues and slow growth rates.

Knowledge of biological factors of individual corals enhances the ability to understand factors that confer resilience and guide management actions in response to threat of elevated sea temperatures and bleaching.

Physical Factors

Certain physical factors may *increase* resistance to bleaching caused by high sea surface temperatures (SSTs):

Cooling: Oceanographic conditions that cause mixing of heated surface waters with cooler deeper water can reduce temperature stress.

Shading: High island shadow or overhanging vegetation may reduce the harmful effects of sunlight.

Screening: Naturally occurring suspended or dissolved matter reduces sunlight penetration and may reduce bleaching.

Stress Tolerance: Coral communities that are exposed to extreme conditions regularly are often populated by species with a high tolerance for stress. Others do not survive.

Conditions only become stressful outside of normal ranges tolerated by the species at its location change. A coral at higher latitudes, for example, may be acclimatized to much lower water temperatures than the same coral species at the equator. A rise above its normal temperature threshold would cause bleaching at temperatures easily enough to cause bleaching when they deviate significantly from those tolerated by the same species at the equator.

On-the-Web

Reef Resilience Toolkit: http://reefresilience.org/Toolkit_Coral/C3_Identifying.html

ARC Center of Excellence for Coral Reef Studies Web Seminar Series:
http://www.coralcoe.org.au/events/webseminar/iyorwebseminar.html

Anticipating Ecological Surprises: Managing Reef Resilience by Terry Hughes:
http://www.coralcoe.org.au/events/webseminar/iyorvideos/terryhughes.html

Bahamas Biocomplexity Project: http://bbp.amnh.org/website/hwg.html

How to kill a coral reef: Lessons from the Caribbean by Bob Steneck:
http://www.coralcoe.org.au/events/webseminar/iyorvideos/bobsteneck.html

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Module 4: Resilient MPAs and MPA Networks

Section 1: Representation and Replication

Learning Objectives

By the end of this lesson you will be able to:

- Identify the three factors of representation to consider and account for in planning MPAs

- Describe the reason for replication and several of the guiding principles to use when applying replication to MPA design

Background

Representation focuses on ensuring that all ecosystems and habitats within the region are represented in the MPA network. Representation at the habitat scale assumes that by representing all habitats, most elements of biodiversity (species, communities, physical factors, etc.) will also be represented in the network. Biodiversity changes locally, regionally, and with latitude. To address the changes in biodiversity across space, each MPA should be carefully placed to capture linked habitats, and to include the diversity of characteristics/conditions of the area. In addition to the biological characteristic of an area, the physical factors across an area need to be represented within the network of MPAs. This helps to build in the resilience by including a variety of conditions that may confer resilience.

When assessing representation for MPA network design, three universal factors should be considered and accounted for in the planning:

- Biodiversity composition: each habitat supports a unique community, and most marine animals use more than one habitat during their lives.
- Biogeographic structure: the environmental/latitudinal gradients in habitats and species composition that should be represented.
- Ecosystem integrity: maintenance of the ecological processes of the system is as important as representing all habitats.

Biodiversity Composition

MPAs should contain many different reef zones and habitats to maintain a full complement of biodiversity, and a steady, varied supply of larvae to replenish damaged areas and to replace dead or emigrated organisms.

Different reef types, depths, and zones within reefs are characterized by different coral assemblages, and different responses to temperature stress and bleaching. There are different species of corals and community types found in shallow lagoons, reef flats and reef crests. Others are found down the reef slope, and may only occur deeper than ~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 be more susceptible to bleaching.

To identify representative and unique habitats, a simple multidimensional classification of habitat, including, but not limited to, depth, exposure, substrate, and dominant flora and fauna is essential in MPA design. In practice, three categories of habitats should be considered for inclusion in coral reef MPAs to attain adequate representation:

1. Coral habitats
2. Contiguous habitats (i.e., submerged, intertidal, or above water)
3. Habitats linked across far distances

Biogeographic Structure

To address the biogeographic structure of the area, the reef type and major reef zones of each bioregion should be protected and geographically represented (e.g., at different latitudes) to reduce potential threats at each site. The MPA should aim to capture the onshore-offshore or habitat-habitat ontogenetic (or life-stage) shifts of species. For example, the MPA should capture the gradient from mangrove to reef as fish move from larval to adult stages, respectively.

Ecosystem Integrity

Ecosystem integrity refers to the degree to which a given area (potential MPA site) functions as an effective, self-sustaining ecological unit. Distinct processes and physical attributes give rise to different coral reef communities; for example, seaward reefs endure greater wave stress than back reef lagoons. These distinct processes are reflected in variations of coral assemblages and zonation patterns. The protection of ecosystem processes is equally important as the protection of all habitats. Representation of physical factors of the area helps to build resilience into the MPA network. MPAs should be placed in areas that capture all major physical characteristics including:

- Exposure
- Energy regimes
- Wave energy

- Weather patterns
- Eddies
- Strong currents

Replication is the inclusion of multiple samples of habitat types in MPAs and networks to spread the risk of large-scale events, such as bleaching. Replication of protected resistant and resilient coral communities at multiple sites increases the probability that some reefs will survive bleaching, and helps the recovery of affected areas.

MPA networks are most effective when each habitat type is represented in more than one MPA. The goal of representation could be met by having only one MPA for each biodiversity element; however, if the habitat is destroyed in the one MPA, representation of that diversity would be compromised, as there would be nothing under protection. Replication provides a buffer against catastrophic loss of an MPA.

To spread the risk of damage or extinction by ensuring that habitat types are replicated in the network, the following guidelines are recommended:

- At the very minimum, three replicates of habitat type should be included, but more is always better. The number of replicates of each habitat type must be a balance between ensuring representation and ensuring effective monitoring and enforcement.
- For large biogeographic areas (100s–1000s km), the MPA should conserve a representative example of each bioregion.
- For smaller areas (1 km–100s km), the MPA should include reef types and major reef zones, which can serve as proxies (or substitutes) for community types.

Replicate MPA sites enable the dispersal of marine species between areas. Many marine species follow a stepping stone model, in which populations exchange larvae with adjacent populations. Replicate MPAs can be designed to accommodate dispersal patterns of species, and facilitate connectivity between the sites. Spacing considerations will also influence fulfilling the stepping stone role of MPAs.

Replication of MPAs also provides analytical power for management comparisons. With more than one MPA, reference, or control sites, can be incorporated into the monitoring program to evaluate the biological changes in and between each of the MPAs. This type of comparison facilitates adaptive management.

Activity: Part 1

Application Exercise: Reef Classification

Goal: To develop a classification map of the major reefs types and zones for your region

Purpose: The reef classification map will be used in the next exercise to identify representative and resilient reefs and replicates for selection as MPAs/zones. It can also be used to develop the sampling design for a rapid response plan for a major coral bleaching.

Group Exercise

Instructions:

1. Delineate major reef types (e.g., atolls, barrier, fringing, patch) and zones (e.g., fore reef, back reef, spur and groove) on your map
2. Identify three factors that explain major coarse divisions in coral reef communities across your region (e.g., wave energy, ocean circulation, isolation)
3. Identify three factors that explain finer level differences (e.g., depth, salinity, turbidity)
4. Apply these factors to differentiate among the reef types and zones on your map
5. Draw divisions on your map and note the reasons.

This should be done using maps provided (or that you brought with you). Use markers to draw boundaries, make notes, or highlight special features on your map. Record your decision-making process in the notes section so that you may return to this activity in the future.

Output: Country map with reef areas classified

On-the-Web

Reef Resilience Toolkit:
http://reefresilience.org/Toolkit_Coral/C5a0_Representation.html

Publications and References

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Section 2: Managing Critical Areas

Learning Objectives

By the end of this section, you will be able to:

- Identify representative and resilient reefs and replicates for selection for MPAs/zoning schematic (using information developed in the reef classification exercise).
- List types of biologically and ecologically significant areas to consider in MPAs
- Identify critical areas to consider in MPA design
- List resistant and resilient factors in coral reefs

Background

It is important to protect communities and systems that are naturally positioned to survive global threats. These areas serve as refuges to secure and maintain sources of larvae to replenish damaged areas. Protection of areas that are known to be resistant or resilient to threats, including bleaching events or other localized impacts, is also important. This section is intended to highlight the importance of considering special biological and ecological elements of a coral reef system.

Ecologically Significant Areas

Biologically and ecologically significant areas include:

- Sources of larvae and spawning aggregations;
- Nursery and breeding grounds of fish and other marine organisms;
- Developmental and feeding habitats; and
- Migration corridors
- Sea turtle nesting areas

Unique or Vulnerable Habitats

The presence of rare, endangered, relict, restricted-range species, and populations with unique genetic composition should be considered for MPA placement. Including unique places in the network will ensure that the network is comprehensive and adequate to protect biodiversity and known sensitive or unique areas. Some marine habitats are more vulnerable to natural and human impacts than others. These habitats include:

- coral reefs
- deep-sea coral communities
- oyster reefs
- salt marshes
- seagrass beds
- mangroves

Resistant Characteristics

Representation of reef communities or coral types that display resistance to bleaching is a vital component of an MPA, and should be afforded high levels of protection, and should be buffered within larger management areas. If a coral reef is resistant, it is more likely to withstand environmental fluctuations or unexpected catastrophes. These resistant communities can play a critical role in reef survival, by providing the larvae to recruit and enable recovery of affected areas.

Resistance Factors in Coral Reefs

Determinants of resistance to bleaching have been identified in some coral communities and species. For example, coral communities that are exposed to extreme conditions on a regular basis (e.g., shallow water or intertidal corals) maintain a higher resistance to bleaching than other non-exposed corals. The following list of resistance factors in coral communities should be considered in any MPA design.

- Localized upwelling of cool water
- Areas adjacent to deep water
- Regular exchanges (cooler waters replace warm water)
- Permanent strong currents (eddies, gyres, tides)
- Wind topography (narrow channel, peninsulas and points)
- High wave energy
- High tidal range
- Shade (from high land profile, undercut coastlines or reef structure)
- Steep slope from coral assemblages and structure
- Presence of naturally turbid water
- Cloud cover
- Exposure to elevated water temperatures (warmer waters in shallow back-reef lagoons)
- Frequent exposure and emergence at low tide
- High diversity and abundance of reef species
- Wide range of coral colony sizes and species distribution
- History of coral survival after bleaching

Considering the above mentioned resistance factors, the following guidelines are recommended:

1. Survey MPAs and their adjacent areas for the presence of environmental factors that cause bleaching resistance, and identify coral communities protected by them.
2. For resistant coral communities *inside* established MPAs, consider securing high levels of protection for them by revising zone boundaries, or establishing 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 creating new MPAs to include them.

Resilient Characteristics

Representation of coral reefs or their components that demonstrate resilience to environmental fluctuations or threats (e.g., bleaching, hurricane, etc.) need to be included in zones with high levels of protection, and should be managed to maintain conditions that facilitate successful coral recruitment and recovery. To maximize both strong and reliable recruitment of all species within the community, and the likelihood that a portion of the recruits will enter surrounding areas, it is important that the MPA includes resilient features.

Resilience Factors in Coral Reefs

The following list of resilience factors in coral reef systems should be considered in any MPA design.

- Availability and abundance of local larvae recruits
- Evidence of recruitment success
- Diversity and abundance of different coral reef taxa, especially high herbivore densities and representative community structure
- Low abundance of bioeroders, corallivores, and diseases
- Effective management regime supported by legal framework, participation and enforcement
- Larval transport and connectivity by currents
- Concentration of larval supply

Considering the above mentioned resilient factors, the following guidelines are recommended:

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 Florida Keys and Mesoamerican Reef Case Studies as examples in the R2 Toolkit.
2. For resilient coral communities *inside* established MPAs, consider securing high levels of protection for them by revising zone boundaries or establishing special zones to encompass these sites.
3. For resilient coral communities *outside* established MPAs, consider extending MPA boundaries to incorporate these sites, if feasible, or creating new MPAs to include them.

On-the-Web

Reef Resilience Toolkit:
http://reefresilience.org/Toolkit_Coral/C5b0_IncludeCriticalAreas.html

Link to recent SST map:
http://www.ssec.wisc.edu/data/sst/latest_sst.gif
http://www.osdpd.noaa.gov/PSB/EPS/SST/climo.html

Link to real-time currents:
http://www.oscar.noaa.gov/datadisplay/index.html

The Angle of the Sun's Rays:
http://www-istp.gsfc.nasa.gov/stargaze/Sunangle.htm

Society for the Conservation of Reef Fish Aggregations
http://www.scrfa.org

Publications and References

The Science of Marine Reserves A Literature Review of Biophysical Guidelines for MPA Network Design and Implementation http://www.piscoweb.org/publications/outreach-materials#booklets

Establishing Resilient Marine Protected Area Networks—Making it Happen

West, J.M., and Salm, R.V. 2003. Resistance and resilience to coral bleaching: implications for coral reef conservation and management. Conservation Biology 17(4): 956-967.

Section 3: Incorporating Connectivity

Learning Objectives

By the end of this lesson, you will be able to:

- Identify the main aspects of connectivity to consider in MPA design
- Describe what is meant by connectivity between adjacent habitats and between distant habitats
- Identify ways to consider larval dispersal and adult population movement patterns into MPA design

Background

A network of MPAs should maximize connectivity between individual MPAs to ensure the protection of ecological functionality and productivity. In this training, connectivity and ecological linkages include:

- Connections of continuous or adjacent habitats such as coral reefs and seagrass beds, or among mangrove and seagrass nursery areas and coral reefs
- Connections through regular larval dispersal in the water column between and within MPA sites.
- Regular settlement of larvae from one MPA to inside another MPA
- Marine life adult movements in their home range, from one site to another, or because of spillover effects from MPAs

It is important to take a system-wide approach in the design of MPA and MPA networks, one that recognizes patterns of connectivity within and among ecosystems (including the linkages among coral reefs, seagrasses, mangroves, watershed, etc.), as well as the connectivity between two populations. The strength of connectivity between locations depends on the abundance and fecundity of source populations, how far larvae disperse before settling to adult habitat, spawning sites and movement patterns of adults, as well as oceanographic effects (e.g., current patterns and retention features).

<u>Adjacent Habitats</u>

Ocean habitat types are connected through the movements of juvenile and adult organisms and through the transfer of materials and nutrients. Adjacent habitat systems are linked through the flow of matter, energy, and organisms. The following adjacent habitat types should be considered in the design of the MPA network:

Reef Flats
Back-reef Lagoons

Seagrass Beds and Sand Flats
Mangroves
Beaches and Dunes

Distant Habitats

Coral reefs are linked to distant areas by dynamic processes (e.g., currents, rivers, and species movements) and may be influenced by activities occurring in remote areas. Distant sources of stress, such as deforestation and development in a watershed, can cause erosion and release sediments that smother reefs. The distant sources of stress may be difficult to identify from a coral reef management perspective, and even more difficult to control.

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. Damaging activities in a linked watershed will need to be controlled by a "ridge to reef" approach to MPA planning, or by coastal zone management approaches that complement MPA planning and management.

Larval Dispersal

Many fish, invertebrates and corals release great numbers of eggs and young into the open ocean. The pelagic larvae can remain floating or moving through ocean currents for hours, days, or even months, traveling distances of 1-1000s of km prior to settling. The distance and the patterns of larval dispersal are influenced by several factors which act synergistically over the pelagic larval duration including: larval behavior and duration, food resources, predators encountered, and currents.

When species-specific larval dispersal data are limiting, dispersal information for a broad range of taxa can be used. Dispersal of a particular species is not as important for the MPA network design as the sum of the larval dispersal for all the species of concern. Generally, species in a community display a range of larval dispersal distances that can be used as a guideline for MPA size and spacing in order to accommodate the dispersal distances of either focal species or the broadest range of species.

The following MPA design principles are recommended to address larval dispersal:

- To compensate for constantly changing ocean conditions, which have impacts on larval dispersal patterns, MPAs should be located in a wide variety of places in relation to the prevailing currents.
- In areas where currents are complex (e.g., eddies or reverse flows), an even spread of MPA locations is recommended.

- In areas where currents are strongly directional, MPAs sited in upstream locations will be more likely to support recruitment to the rest of the management areas than those in downstream locations.
- A network of MPAs linked to each other by prevailing currents will facilitate the recovery of damaged areas, and the maintenance of biodiversity through larval exchange.

<u>Adult Movement Patterns</u>

The movement patterns of adult species are important to consider in MPA design. How much protection an MPA affords a species depends (to some degree) on movement habits and distances of the individual (both as adult and larvae).

If adults move widely, the ocean neighborhood is large and diffuse. If adults are sessile, then the ocean neighborhood might be small and distinct.

The following MPA design principles are recommended to address adult movement patterns:

- Gather information on target species adult movement distances and patterns. Information about the species' ocean neighborhood can provide insights to help guide MPA size and spacing. For example, the size of the MPA can be based on adult neighborhood scales of highly fished species to ensure that at least some adults remain protected during the adult life stage.
- Ultimately, an MPA that accommodates species with the largest adult movement patterns should protect species with smaller adult movement distances as well. For example, MPAs designed to ensure self-seeding for species that move up to 100 km as adults should be sufficient for self-seeding of species that move only 10 km as adults.

On-the-Web

Reef Resilience Toolkit:
http://reefresilience.org/Toolkit_Coral/C5c0_IncorpConnectivity.html

CCAR Real-Time Altimeter Data Group http://argo.colorado.edu/~realtime/gsfc_gom-real-time_ssh/

PISCO http://www.piscoweb.org/

Publications and References

Jones, G.P., Srinivasan, M. and Almany, G.R. 2007. Population connectivity and conservation of marine biodiversity. Oceanography 20(3):12

Kinlan, B.P. and Gaines, S.D. 2003. Propagule dispersal in marine and terrestrial environments: a community perspective. Ecology 84 (8): 2007-2020.

Managing Mangroves for Resilience
http://www.reefresilience.org/pdf/Managing_Mangroves.pdf

Palumbi, R.S. 2004. Marine reserves and ocean neighborhoods: The spatial scale of marine populations and their management. Annual Review of Environment and Resources 29: 31-68.
http://www.tos.org/oceanography/issues/issue_archive/issue_pdfs/20_3/20.3_jones_et_al.pdf

Sale, P.F., Cowen, R.K., Danilowicz, B.S., Jones, G.P., Kritzer, J.P., Lindeman, K.C., Planes, S., Polunin, N.V.C., Russ, G.R., Sadovy, Y.J., and Steneck, R.S. 2006. Critical science gaps impede use of no-take fishery reserves. Trends in Ecology and Evolution 20 (2): 74-80.

Section 4: Size, Shape, and Spacing

Learning Objectives

By the end of this lesson, you will be able to:

- Describe the basic guidelines on sizing for MPAs
- Describe core-zones
- Identify the two main aspects of spacing that need to be considered in MPA design
- Describe the two components of shape to consider in the design of an MPA

Background

The size, shape and spacing of individual MPAs in an MPA network greatly influence the degree to which conditions in the wider environment affect the features of the MPA, and exchange of individuals between the MPA and adjacent environment. The three components of size, spacing, and shape should be considered in design of the MPA network to facilitate and promote connectivity between and within the MPA network.

Deciding how many, how large, and how far apart MPAs should be is a challenge. Ultimately, size, shape and spacing design of an MPA network will vary with the goals and objectives of the MPA, as well as the social and economic environment in which it is located. However, there are some general design guidelines on size, shape and spacing of each MPA that will help to ensure maximum benefits to individual MPAs within a larger MPA network

Size Matters

The size of an MPA should take into consideration the need for large populations to insure against catastrophes, as well as the patterns of connectivity. Even small sized MPAs can provide positive benefits, in terms of fish biomass, size and abundance, but a single, small MPA provides insufficient protection to large populations of many species. In general, bigger MPAs can protect more habitat types, more habitat area, larger populations of species, and a greater number of species in the ecosystem.

The ideal size of MPAs for biodiversity conservation will generally be larger than those planned for fish stock protection and enhanced recruitment. In terms of fisheries, as MPA size increases, the potential fisheries benefit from spillover and larval recruitment will increase, but only to a certain point, and only if those targeted species are protected. General MPA size principles that apply to the entire MPA network are provided in the following recommendations:

- Aim for 10-20 km in diameter, across MPA minimum width.

- In terms of biodiversity protection, fewer large MPAs are preferable to a greater number of smaller ones.
- To meet both fishery and conservation goals, intermediate sizes of MPAs, and a variation of sizes within a network may be ideal.
- Consider feasibility of management. A smaller MPA is easier to enforce, and the monitoring efforts are less demanding. Larger MPAs take longer to establish and implement, and require greater financial support.

No-take Areas

Coral bleaching events have demonstrated that replenishment is an important consideration for reef survival, regardless of the management objective. The effects of bleaching cannot be lessened by MPA zones, boundaries, regulations, or management efforts. Therefore, MPAs should be designed specifically to meet the requirements for reef survival. MPAs need to be large enough to be self-replenishing and sustainable. The optimal size of an MPA is designed around a strictly protected, no-take zone, or 'core zone', which encompasses sufficient target coral areas to be self-replenishing. To support self-replenishing MPAs, the following no-take zone guidelines are recommended:

- The no-take area should be selected to encompass a diverse range of reef habitats.
- The no-take area should be as large as possible to preserve a high diversity of reef biota.
- Large reefs may be self-replenishing, because their size allows portions of reefs damaged by bleaching, slumping (collapse of the reef slope), storm surges, freshwater flooding, or other stresses, to be replenished by recruits from undamaged parts of the same reef.
- To ensure self-seeding, the MPA should be as large as the mean larval dispersal distance of the target species.

Optimal Spacing

The exchange of larvae and adult organisms among MPAs is the fundamental biological rationale for MPA networks. To function as an effective network, the MPAs should be spaced to facilitate the connectivity between one another. Spacing of individual MPAs within the network is critical to maximize recruitment outside the MPAs. The design of the network of MPAs should: (1) accommodate the long distance dispersal of larvae; (2) capture the biogeographic range of variation in habitats and species.

Movement out of, into and between MPAs by adults, juveniles, larvae, eggs, or spores of marine organisms depends on their dispersal distance, and guides spacing aspects of MPA network design. In general, the lower the effective larval dispersal of a species, the closer the MPAs will have to be to provide benefits to unprotected areas. MPAs that are more closely spaced are more likely to be ecologically connected and serve to protect a greater number of species through movement of young and increased recruitment from other MPAs. Therefore, MPAs should be spaced appropriately to capture the broadest range of dispersal distances as possible.

MPA spacing is habitat dependent. Habitat distribution patterns should influence where the MPAs are placed and how they are spaced. Within an MPA network, what matters is not spacing to the next MPA, but spacing to the next MPA that offers suitable habitat for the target species (or range of target species). Based on the habitat distribution or larval dispersal of the target species, spacing between MPAs can be established.

In general, the following spacing guidelines are recommended:

- To facilitate dispersal and promote connectivity between MPAs, MPAs should be placed appropriately to capture the middle range of dispersal distances. It is recommended that MPAs should be placed within 10 - 20 km of one another to capture effective connectivity.
- MPAs should be spaced to capture the biogeographic range of variation in habitat and species.
- Variable spacing is better than fixed spacing when there are several small reserves rather than a few large reserves (as long as they are within this 10-20km range)

<u>Shape Matters</u>

There are two components of shape to consider in the design of an MPA: edge effects and enforceability.

Edge Effects : In the design of an MPA, it is important to consider the ratio of edge habitat versus core interior habitat, as the edges (or perimeter boundary line) of MPAs are often extensively fished, and therefore do not offer the same refuge to fish species as the interior protected areas do. Juvenile and adult spillover from the MPA is edge-dependent, and as the amount of edge of an MPA increases, faster export is expected, relative to the total protected area. It is important to **minimize edge habitat and maximize interior protected area.**

Enforceability: The shape of an MPA is also a critical factor in effective delineation and enforcement. A shape that allows for clear marking of boundaries for both resource users and enforcement personnel may increase effectiveness. MPAs with boundaries that conform to natural habitat edges offer fuller protection than MPAs with boundaries that cross reef habitat types and zones. However, the ease of compliance and enforcement capabilities need to be taken into account.

- MPAs should be contiguous, compact and easily delineated.

- Consider obvious, easy GPS reference points, such as landmarks and distinct habitat types.
- Regular MPA **shapes of squares or rectangles are preferable** because they can be delineated by lines of latitude and longitude, and therefore more easily identified by user groups.

On-the-Web

Reef Resilience Toolkit:
http://reefresilience.org/Toolkit_Coral/C5d0_SizeSpacing.html

Publications and References

Gaines, S.D., Gaylord, B., and Largier, J.L. 2003. Avoiding current oversights in marine reserve design. Ecological Applications 13(sp1): 32-46

Green, A., Lokani, P., Sheppard, S., Almany, J., Keu, S., Aitsi, J., Warku Karvon, J., Hamilton, R. and Lipsett-Moore G. 2007. Scientific design of a resilient network of Marine Protected Areas. Kimbe Bay, West New Britain, Papua New Guinea. TNC Pacific Island Countries Report No. 2/07.
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Halpern, B. 2003. The Impact of Marine Reserves: Do Reserves Work and Does Reserve Size Matter? Ecological Applications 13(1): S117-S137
http://www.nceas.ucsb.edu/~halpern/pdf/Halpern_EA_2003.pdf

Halpern, B.S., Regan, H.M., Possingham, H.P., and McCarthy, M.A. 2006. Accounting for uncertainty in marine reserve design. Ecology Letters 9(1): 2-11.
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Sala, E., Aburto-Oropeza, O., Paredes, G., Parra, I., Barrera, J.C., and Dayton, P.K. 2002. A General Model for Designing Networks of Marine Reserves. Science 298: 1991-1993.
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Shanks, A. L., B. A. Grantham and M. H. Carr (2003). Propagule Dispersal Distance and the Size and Spacing of Marine Reserves. Ecological Applications 13(1): S159-S169.

Section 5: Socioeconomic Criteria

Lesson Objectives

By the end of the lesson, you will be able to:

- Identify the main sectors that socioeconomic efforts tend to focus
- Describe ecosystem services and identify the four main groups of services
- List the ecosystem services that should be considered and how to measure them for MPA planning

Background

Social and economic criteria should always be considered when creating a resilient MPA network. The challenge is how to integrate requirements of natural systems with needs of the people who depend upon them. An effectively managed, resilient MPA network is one way to address this challenge. MPA creation can help move from single sector management to a more holistic approach, including human and ecosystem interactions, and cumulative impacts. This multiple-objective approach can create a foundation that transforms the way people address conflicts between the environment and the economy.

Although all social and economic factors, including the costs and benefits to humans and the environment, should be considered in creating an MPA network, the majority of efforts tend to focus on:

Tourism: Often a majority of income, especially in developing countries, comes from tourism. It is important to create tourism industries with limited biodiversity impacts, local knowledge that is used for tours and management, and buy-in from the local community to be stewards for their natural resources.

Fisheries: Commercial and some artisanal fishing can have the largest impacts, and be most impacted by MPA networks. Local fishers may have to learn new trades or fish with alternative gear to ensure their livelihoods are secure. Support and buy-in from the local community, stakeholders, and government is imperative to a successful and sustainable MPA network.

Other (climate change, ports/marinas, coastal development): Creating a successful resilient MPA network depends on accounting for the many effects of climate change, some of which are addressed in this toolkit. In addition, there will always be multiple uses in or near an MPA. Working with the community and multiple stakeholders to create a win-win situation for everyone is key.

Ecosystem Services

What are Ecosystem Services?

1. Humankind benefits from a multitude of resources and processes that are supplied by natural ecosystems. Collectively, these benefits are defined as “ecosystem services” and include products like clean drinking water, and processes like the decomposition of wastes. The Millennium Assessment has identified four groups of ecosystem services: Provisioning (e.g., subsistence and commercial fisheries attained from healthy reefs)
2. Regulating (protection of beaches and coastlines from storm surges and waves)
3. Cultural (tourism and recreation)
4. Supporting (nursery habitats)

Ecosystem services are distinct from other ecosystem products and functions, because there is human demand for these natural assets.

As human populations grow, so do resource demands imposed on ecosystems and impacts of our global footprint. For many years, people have assumed that these ecosystem services are free and infinitely available. However, impacts of anthropogenic use and abuse are becoming more apparent, especially around coral reefs: oceans are being overfished, invasive species are extending beyond their historical boundaries, and deforestation is eliminating flood control around human settlements. Consequently, society is now realizing that ecosystem services are not only threatened and limited, but that the need to evaluate trade-offs between immediate and long-term human needs is urgent.

To help inform decision-makers, economic value is increasingly associated with many ecosystem services, and often based on the cost of replacing these services with human derived alternatives, such as installing a breakwater where the natural system that used to provide a barrier has been destroyed. The on-going challenge of prescribing economic value to nature is prompting shifts in how we recognize and manage the environment, social responsibility, business opportunities, and our future as a species.

What Services Should Be Considered?

Since there are many ecosystem services that benefit humans it is important to include them in management plans. These services have been well reviewed and defined in the Millennium Assessment, and the other links on this page.

Often the provisioning and cultural services of fisheries and tourism, respectively, are considered in MPA management plans. However, regulating and supporting services should also be reviewed, valued if possible, and represented in any resilient MPA network. A healthy reef will be able to provide multiple services to the community that depends on it; including the services the reef provides in management plans is one way to ensure reef health.

Measuring Ecosystem Services

There are many methods by which to measure ecosystem services. However, it should be noted that the values that are determined from these methods, whether in dollars, number of jobs, or tons of fish, should be kept in perspective and evaluated within the larger context of how they will contribute to reef health.

Using Ecosystem Services Information

Once services have been measured, or at least accounted for, managers can use this information to:

- Prioritize which areas should be protected/restored
- Balance between extractive and conservation uses
- Balance between sustainable harvesting and ensuring healthy reefs for biodiversity and tourism goals

On-the-Web

Reef Resilience Toolkit:
http://reefresilience.org/Toolkit_Coral/C5e0_Socioeconomic.html
Kimbe Bay Case Study: http://www.reefresilience.org/Toolkit_Coral/C8_Kimbe.html
NOAA Coasts: http://www.noaa.gov/coasts.html
Biodiversity of Economics: http://pdf.wri.org/cesardegradationreport100203.pdf
SOCMON: http://www.reefbase.org/socmon/default.asp?redirect=home_04

Publications and References

The Economics of Worldwide Coral Reef Degradation (links to many MPA papers):
http://pdf.wri.org/cesardegradationreport100203.pdf

Activity: Part 2

Application Exercise: MPA Design/Zoning

Purpose: Using information developed in the reef classification exercise, identify representative and resilient reefs and replicates for selection for MPAs/zoning schematic. This preliminary work can be used to begin the process of designation or consideration of zones in existing managed areas with stakeholders at your site(s).

Group Exercise

Instructions:

Based on the information you developed in the classification exercise and the criteria listed below, choose a portfolio of MPA sites for your country or zoning scheme for your site. This should be done using maps provided (or that you brought with you). Use markers to draw boundaries, make notes, or highlight special features on your map. Record your decision-making process in the notes section so that you may return to this activity in the future.

Step 1: Review criteria below to further describe your area

- Good example of reef or habitat type
- Good condition
- High biodiversity
- Low level of threat
- Survived bleaching
- Recovering well from bleaching mortality or disturbance
- High habitat complexity
- Replicates of the above at regular intervals (20 km where possible) by Latitude/Longitude

Step 2: Identify Critical Areas

Step 3: Choose a portfolio of MPA sites for your country or zoning scheme for your site using what you've learned about resilience and rules of thumbs for connectivity, critical areas, size, shape, spacing, and socioeconomic criteria

Step 4: Peer review your work within your group (if more than one country)– prepare to report back in a 30 minute poster session at end of exercise

Output: Country map with MPA or MPA network design/zoning scheme

Rules of Thumb Checklist for MPA/Network Design

Representation & Replication

- Good representation of habitat types, structure, function, physical conditions
- Minimum of 3 replicates of each habitat type/condition (classified area)

Critical Areas

- Inclusion of important nesting, breeding, and nursery grounds
- Inclusion of special areas (e.g., likely resilience/resistance to bleaching, ecologically sensitive areas)

Connectivity

- Inclusion of known 'source' areas
- Protection of habitat linkages (e.g., reef to seagrass to mangrove)

Size, Spacing, Shape

- 10-20 km diameter at minimum width
- Fewer large better than many small
- 10-20 km between core zones or MPAs
- Regular shapes easy to delineate and enforce (e.g., squares, rectangles, straight lines)

Socioeconomics

- Consider locations away from industrial areas or other high impact land use areas
- Consider existing activities that may be impacted or have negative impact on MPA (e.g., traditional use, commercial use, recreational use)
- Consider user conflicts to minimize future problems

Module 5: Assessing Mass Coral Bleaching, Resilience, and Socioeconomic Impacts

Section 1: Assessing the Ecological Impacts of Mass Coral Bleaching

Learning Objectives

By the end of this module you will have:

- An understanding of 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.

Background

In previous modules, you learned about the impacts of climate change to coral reefs and what resilience is and how to identify factors that confer resilience. This module will provide a overview of how to assess the ecological and socioeconomic impacts of mass coral bleaching and how to incorporate resilience into monitoring programs. This section deals with one of the first steps in a 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 stakeholders, managers, government departments and the media. One goal of this section is 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. To that end, another goal of this section is to provide managers with the ability to identify resilient reef areas and incorporate resilience monitoring into bleaching assessment protocols.

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 section 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. These techniques will allow managers to gather sufficient information to report to concerned 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. Maintenance of long-term monitoring programs will enable managers to detect gradual changes in coral community structure that may occur because of 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. Rather than dictate to managers which assessment protocols should be used, this section highlights the relative benefits and weaknesses of a range of assessment approaches so that managers can make the best choice of methods to be included in a bleaching response plan.

On-the-Web

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://reefcheck.org/ecoaction/Monitoring_Instruction.php

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

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

Publications and References

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.

Hansen, L.J., J.L. Biringer and J.R. Hoffman . 2003 Buying Time: A User's Manual to Building Resistance and Resilience to Climate Change in Natural Systems. http://www.panda.org/news_facts/publications/index.cfm?uNewsID=8678

Section 2: Monitoring for Resilience

Learning Objectives

- Knowledge of the reef characteristics that may promote resilience to bleaching.
- The ability to use bleaching events to identify resilient reef areas.
- Understand resilience protocols that are available for you to use and modify
- Understand the importance of incorporating resilience monitoring into your traditional monitoring practices.

Background

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.

Recently the IUCN has been working on a rapid resilience assessment protocol. The following information comes from the *IUCN Resilience Assessment of Coral Reefs: Rapid assessment protocol for coral reefs focusing on coral bleaching and thermal stress*. The need for rapid methodologies for measuring coral reef resilience and their application in assessing the effectiveness of coral reef conservation management measures is becoming increasingly acute, and especially so in the developing world. It is therefore crucial to develop monitoring and assessment protocols to build an understanding of bleaching resistance and resilience indicators for application in management, and to determine how MPA management actions can influence resilience and resistance. The IUCN Resilience Assessment Methodology is designed to provide a rapid assessment of coral bleaching resistance and resilience at an individual site level. This is intended to facilitate assessment of any past management actions in maintaining the resilience of coral reefs, and the making of new management decisions against local MPA objectives.

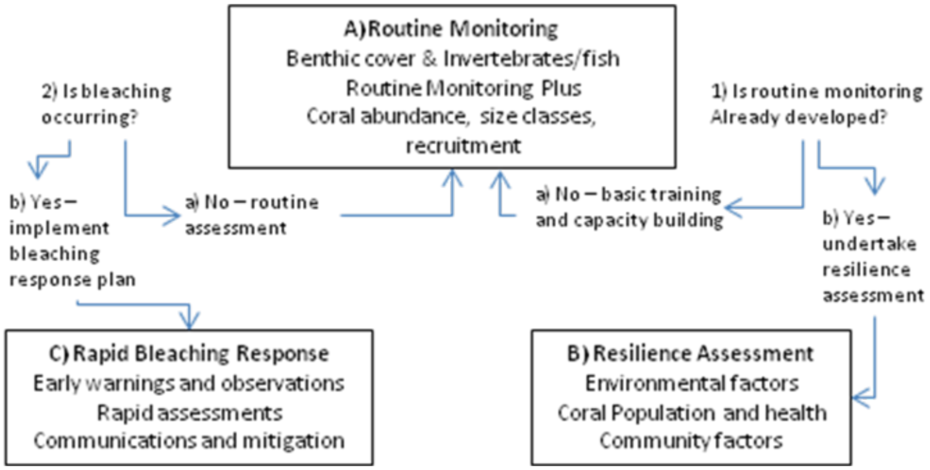
Specifically, the protocol is intended to:

1) Assess the factors affecting coral bleaching during a bleaching event (resistance factors).
2) To assess the factors affecting coral and reef recovery following a bleaching event (resilience factors).
3) Enable between-site comparisons at a local area/region/MPA (network) level.
4) Enable inter-regional comparisons at larger scales.

In a management context, the protocol should facilitate:

5) Building an understanding of bleaching resistance and resilience factors that can be addressed by MPA design and management.
6) Assessing whether MPA design and management practices to date have addressed bleaching resistance and resilience.
7) Designing networks of MPAs based on bleaching resistance/resilience characteristics.
8) Providing information to adaptively manage coral reefs in response to bleaching events and reef resilience.

While the assessment protocol can be undertaken as an independent study, it is most useful in an adaptive management structure that already incorporates annual or routine monitoring. Thus routine monitoring (A) provides background time series information on a limited set of variables that track coral reef status and function over time. Where the concern is about the effects of coral bleaching, this resilience assessment is designed to be undertaken to increase understanding of the resistance and resilience of reefs to bleaching, whether a bleaching event has occurred in the past or not (B). This need be done only once, then again after a long period (e.g. 5 years) or after a major event (e.g. bleaching, or other major pulse stress such as a cyclone, COTs outbreak, etc.) to determine whether the reef has been shifted into another phase. During a bleaching event, a separate monitoring approach is applied focused just on bleaching variables, designed to be repeated over short periods of time (e.g. monthly) to track the actual event (C).



Nested approach to monitoring resilience, building additional resilience indicators onto routine monitoring approaches (step 1b). During a bleaching event (step 2b) a subset of resilience indicators would be included in bleaching assessment protocols (Oliver et al. 2004). (Source: *IUCN Resilience Assessment of Coral Reefs: Rapid assessment protocol for coral reefs focusing on coral bleaching and thermal stress*)

The Resilience Assessment Methodology will be available in a publication from IUCN which includes survey design, field methods to assess coral condition, algae, fish and resilience factors and well as data management and analysis.

The IUCN is just one protocol of many that is available. In the Caribbean region the Atlantic and Gulf Rapid Reef Assessment (AGRRA) protocol is widely used and there may be other protocols designed for your areas.

The Nature Conservancy Reef Resilience (R^2) Toolkit, on which portions of this workshop are based, provides a good review of the resilience principles for and incorporating resilience into coral reef management. We will discuss the incorporation of resilient areas and into MPA design in a later module. Broader guidance beyond MPA design for increasing reef resilience can also be found in the Tropical Marine chapter of Buying Time which can be found at http://assets.panda.org/downloads/6chapter6.pdf.

On-the-Web

Florida Reef Resilience Program: www.frrp.org/

TNC Reef Resilience Toolkit: www.reefresilience.org

Atlantic and Gulf Rapid Reef Assessment Protocol: www.aggra.org

IUCN Resilience Assessment of Coral Reefs:
http://cmsdata.iucn.org/downloads/resilience_assessment_final.pdf

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Nyström, M., and Folke, C. 2001. Spatial resilience of coral reefs. Ecosystems 4: 406–417.

Section 3: Assessing and Predicting Socioeconomic Impacts of Climate Change

Learning Objectives

- An understanding of the why we need to assess the socioeconomic impacts of mass coral bleaching and climate change.
- An understanding of the potential socioeconomic impacts of coral bleaching and mortality, as well as other impacts from climate change.
- The ability to identify impacted populations.
- An understanding of the steps necessary to undertake a socioeconomic assessment.
- An understanding of developing and using scenarios in vulnerability and adaptation assessment
- Heard about several case studies to illustrate results of previous socioeconomic assessments in Philippines, Palau, American Samoa, Bonaire, Barbados, and the Western Indian Ocean.

Background

Climate change impacts on coral reef ecosystems may also have subsequent flow-on effects for coastal communities who depend on reefs for a range of ecosystem goods and services. When corals bleach, impacts occur not only to ecological communities but also to the human communities who depend upon coral reefs for income, food from fisheries, revenue generation from tourism, recreation, cultural traditions, and educational opportunities. If corals recover from bleaching events, these impacts may be temporary. However, if corals die as a result of bleaching, impacts may be longer-term and more severe. Ironically, social, cultural, and economic impacts can also occur as a result of management interventions aimed at promoting coral reef resilience to climate change. Managers need to understand the relationship of the communities with the coastal and marine resources. At the same time, they need to find out how climate change and management decisions related to climate change will impact the socioeconomic aspects of communities who depend upon reefs so that they can design and implement strategies that will meet both environmental and socioeconomic needs. This section aims to provide managers with basic knowledge of the components of a socioeconomic assessment and ways to perform assessments. In the following section we will discuss some specific manuals available that outline the steps for socioeconomic assessment, and for developing of socioeconomic scenarios for vulnerability and adaptive assessments. Several case studies have been provided to illustrate how other communities have undertaken such assessments and the outcomes of these assessments. These case studies show how difficult it can be to separate out the socioeconomic impacts of bleaching from impacts from concurrent events, such as regional economic downturns, weather events, or other stresses on corals. This section aims to incorporate socioeconomic monitoring into bleaching assessment protocols.

Reef managers, policy-makers, and communities that understand the relationships people have with the adjacent coral reefs will be able to better identify both the impacts of a mass bleaching event and any impacts associated with management strategies. This knowledge can be used to design management strategies that maximize environmental outcomes while minimizing negative impacts on people. Specifically, impact assessments can:

- → Identify the potential social and economic impacts of mass bleaching;
- → Integrate local knowledge with technical expert knowledge;
- → Evaluate the social and economic costs and benefits of various coral bleaching management strategies; and
- → Increase public involvement in the monitoring of coral bleaching.

Given how difficult it can be to separate the socioeconomic impacts of bleaching from impacts from concurrent events, some communities may wish to undertake general economic valuation studies for their coral reefs, which could be used to derive impacts from bleaching with a small amount of additional data collection. These valuation studies can also be used as a baseline from which to measure socioeconomic impacts of bleaching and other damaging events.

In addition to impacts from coral bleaching, climate change and variability will catalyze other impacts as well. In the Pacific island region, the current most visible impacts from climate change also include sea level rise, inundation, salt water intrusion, and coastal erosion. Climate change is having increasingly impacts on livelihood, food security, infrastructure, human health, and the most important economic bases of the Pacific islands, namely fishery, agriculture and tourism. Quantification of these impacts to the tourism industry has been attempted in several cases, with significant economic consequences predicted for climate change.

Worksheet or Activity

Worksheet: Socioeconomic Considerations in your Bleaching Response Plan

Activity 3: Selecting Socioeconomic Indicators

SOCIOECONOMIC CONSIDERATIONS

It is important to consider the impacts to human users of coral reefs from climate change and coral bleaching. impacts, from the bleaching itself, especially when there is coral mortality, and indirect impacts from manager

Use this table to identify populations who may be affected by major coral bleaching events. These impacts w to the media and to elected officials. It is also important to understand up front the economic impacts of certa measures (e.g. dredging bans during bleaching events).

Moderate bleaching	1.		
	2.		
	3.		
Severe bleaching	1.		
	2.		
	3.		
Post-bleaching coral mortality	1.		
	2.		
	3.		
Indirect impacts			
Fishing restrictions	1.		
	2.		
Recreational use restrictions	1.		
	2.		
Restrictions on coastal development/ dredging	1.		
	2.		
Other:			

Activity 3: Defining socioeconomic assessment objectives and selecting relevant socioeconomic indicators

Given scenario: A coastal community of 10,000 people experiencing the following impacts:

- Climate: Rising sea surface temperature
- Biological impacts: Mass coral bleaching, coral mortality, decreasing abundance and availability of fish stocks
- Physical impacts: Weaken reef structure, more exposure for coastal erosion during storm surge events

Your tasks:

1. Define your socioeconomic assessment objectives:

2. From the examples of socioeconomic indicators presented in the Powerpoint presentation, select ones that are relevant and appropriate for the above objectives. Propose a data collecting method for each of the selected indicators. The methods include secondary sources, household survey, key informant interview, focus group discussion, and observation.

Socioeconomic assessment tools:

Global Socioeconomic Monitoring Initiative (SocMon):
http://www.reefbase.org/socmon/

Locally Managed Marine Areas Network (LMMA): http://www.lmmanetwork.org

Malone, Elizabeth L., Joel B. Smith, Antoinette L. Brenkert, Brian Hurd, Richard H. Moss, and Daniel Bouille. 2004. Developing Socioeconomic Scenarios for Use in Vulnerability and Adaptation Assessments. New York: UNDP. http://ncsp.undp.org/docs/653.pdf.

Mersai, Charlene T and Craig J. Severance. No date. Introductory Handbook for Biological and Social Monitoring of MPAs in Palau. Koror: Palau International Coral Reef Center.

Nakalevu, Taito. 2006. CV&A : A Guide to Community Vulnerability and Adaptation Assessment and Action. Apia, Samoa : South Pacific Regional Environment Programme (SPREP). http://www.sprep.org/att/publication/000437_cvaguidee.pdf

Wongbusarakum, S. and R. Pomeroy. 2008. Socioeconomic Monitoring Guidelines for Coastal Managers in Pacific Island Countries. Silver Spring: National Oceanic and Atmospheric Administration; and Apia, Samoa: Secretariat of Pacific Regional Environment Programme. http://www.reefbase.org/socmon/pdf/SocMon_Pacific.pdf

World Wildlife Fund. 2007. Climate Witness Community Toolkit. Suva, Fiji: World Wildlife Fund-South Pacific Programme. http://assets.panda.org/downloads/cw_toolkit.pdf

Economic valuation studies

Cesar, H., P. van Beukering, S. Pintz, and J. Dierking. 2002. *Economic Valuation of the Coral Reefs of Hawaii.* Final report to National Oceanic and Atmospheric Administration Coastal Ocean Program. Cesar Environmental Economics Consulting, Arnhem, The Netherlands. http://marineeconomics.noaa.gov/Reefs/HICesar.pdf Accessed on April 24, 2008.

Socioeconomic Monitoring Program for the Florida Keys National Marine Sanctuary - Recreation/Tourism: http://marineeconomics.noaa.gov/SocmonFK/Linking.html

Valuing the Environment in Small Islands - An Environmental Economics Toolkit
http://www.jncc.gov.uk/page-4065

World Resources Institute (WRI) Economic Valuation of Coastal Ecosystems in the Caribbean: *http://www.wri.org/project/valuation-caribbean-reefs*

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Bell, Johann D., Mecki Kronen, Aliti Vunisea, Warwick J. Nash, Gregory Keeble, Andreas Demmke, Scott Pontifex , Serge Andrefouet. 2009. Planning the use of fish for food security in the Pacific. *Marine Policy* 33: 64-76.

Cesar, H., L. Pet-Soede, M. C. C. Quibilan, P. M. Aliño, H. O. Arceo, I. V. Bacudo and H. Francisco, 2001. First Evaluation of the Impacts of the 1998 Coral Bleaching Event to Fisheries and Tourism in the Philippines. Pp. 41-58 in Schuttenberg, H.Z. (ed.). *Coral Bleaching: Causes, Consequences and Response.* Selected papers presented at the Ninth 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.

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Graham, T., N. Idechong and K. Sherwood, 2001. The Value of Dive-Tourism and the Impacts of Coral Bleaching on Diving in Palau. Pp. 59-72 in Schuttenberg, H.Z. (ed*.). Coral Bleaching: Causes, Consequences and Response*. Selected papers presented at the Ninth 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.

Johns, Grace M., Vernon R. Leeworthy, Frederick W. Bell, Mark A. Bonn. 2001. *Socioeconomic Study of Reefs in Southeast Florida*. Final Report October 19, 2001 for Broward County, Palm Beach County, Miami-Dade County, Monroe County, Florida Fish and Wildlife Commission, and National Oceanic and Atmospheric Administration.

Malone, Elizabeth L., Joel B. Smith, Antoinette L. Brenkert, Brian Hurd, Richard H. Moss, and Daniel Bouille. 2004. *Developing Socioeconomic Scenarios for Use in Vulnerability and Adaptation Assessments*. New York: UNDP. http://ncsp.undp.org/docs/653.pdf.

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Pet-Soede, Lida. 2000. Effects of coral bleaching on the socio-economics of the fishery in Bolinao, Pangasinan, Philippines.

Schuttenberg, Heidi and Paul Marshall. 2006. *A Reef Manager's Guide for Coral Bleaching*. Townsville, Australia: Great Barrier Reef Marine Park Authority. http://www.coris.noaa.gov/activities/reef_managers_guide/pdfs/reef_managers_guide.pdf Accessed on April 15, 2008.

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United Nations Development Programme. 2004. *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*. http://ncsp.undp.org/report_detail.cfm?Projectid=151

United States Agency for International Development. 2007. *Adapting to Climate Variability and Change: A Guidance Manual for Development Planning*. Washington D.C. http://www.usaid.gov/our_work/environment/climate/docs/reports/cc_vamanual.pdf

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Van Beukering, P., editor. *The economic value of the coral reefs of Saipan, Commonwealth of the Northern Marina Islands.* February 2006. Prepared by Cesar Environmental Economics Consulting under contract to the National Oceanic and Atmospheric Administration.

Van Beukering, P., editor. *The economic value of Guam's coral reefs*. March 2007. University of Guam Marine Laboratory Technical Report No. 116.

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Socioeconomic Impacts, Future Trends and Mitigation Planning.” Coastal Management Report #2230, Coastal Resources Center, University of Rhode Island: 102 pp.

Module 6: Building Resilience into Coral Reef Management

Section 1: Social-Ecological Resilience

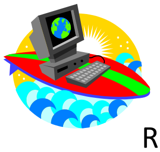
Learning Objectives

By the end of this module you will:

- Understand the term socio-ecological resilience
- Be able to incorporate resilience monitoring into a bleaching response plan
- Learn how to incorporate the concept of socio-ecological resilience into coral reef management
- Heard about examples of integrating social-ecological resilience into management in Marshalls, American Samoa, Kenya and Papua New Guinea.

Background

In previous sections we learned how to identify the impacts of climate change on ecosystems and socioeconomic systems of stakeholders. We also learned how socioeconomic information can help improve the coastal management under changing climate. This section discusses how we might incorporate social-ecological resilience into coral reef management. We provide principles of building social resilience and examples of cases in which social and ecological information can be integrated and used to adapt coral reef management planning. Resilience to climate change is an emerging concept in coral reef management, and much of the science behind resilience is still in the early stages. Likewise, incorporating social and ecological resilience into management is a relatively new concept for coral reefs. In this section we will seek input from managers on the practicality of strategies for incorporating resilience into management, and seek feedback on how manages perceive that these concepts may work in their respective regions.



On-the-Web

Reef Resilience R^2 Toolkit: http://www.reefresilience.org/

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http://www.icriforum.org/library/Reso_CC_Tokyo_0407.pdf

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Schuttenberg Heidi, Colleen Corrigan, Lizzie McLeod, Paul Marshall, Naneng Setiasih, David Obura, Ove Hoegh-Guldberg, Billy Causey, Mark Drew, Lara Hansen, Gabriel Grimsditch, Jordan West, Andrew Skeat, Mark Eakin, Laurence McCook, Maurice Crawford, Phil Kramer and Stuart Campbell 2006 *Building resilience into coral reef* *management: key findings & recommendations.* Conference proceedings of the International Tropical Marine Ecosystem Management Symposium 2006, Cozumel, Mexico. http://www.itmems.org/itmems3/pr_resilience.html

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http://www.tyndall.ac.uk/publications/surviving.pdf

Section 2: Responding to Bleaching Events: Interventions

Learning Objectives

By the end of this module you will:

- Understand that managers can do something locally to respond to mass bleaching events
- Understand coral reef "triage" and restoration options available for MPA managers to implement in response to severe mass coral bleaching
- Understand a range of short-term, local strategies for coral bleaching management:
    - Area closures: visitor/fishing pressure reduction
    - Cooling waters: experimental induction of localized upwelling
    - Water circulation manipulations
    - Shading strategies
    - Sea surface condition manipulations
    - Minimize human-induced sedimentation impacts
    - Improve water quality
- Understanding of the considerations for assessing whether restoration intervention is a viable strategy.
- Understand a range of options for restoration intervention:
    - Habitat & ecosystem function modification
    - Species re-introduction
    - Enhancement of recruitment
    - Disease treatment intervention programs
    - Coral transplantation

Background

Managers may feel helpless to act in the face of a mass bleaching event, but there are several intervention strategies that managers can take to help coral reefs resist and recover from temperature stress. This section provides a range of strategies to minimize additional stress on coral reefs during bleaching events, so that corals are given the greatest chance of resisting warm water events. Emerging strategies to impede the causes of mass bleaching are discussed, such as reducing the amount of light and heat reaching corals. We also discuss potential strategies to reduce physical stresses reduce corals' ability to resist bleaching. These strategies include limiting activities such as snorkeling, diving and boat anchoring during bleaching. We also explore options that may accelerate natural recovery following bleaching mortality. We discuss the need for managers to weigh the value of reef restoration against the potentially high cost. Many of the proposed strategies in this section are still in the experimental and early developmental stages and their future success is largely unknown. Managers may contribute towards the urgent need to identify viable strategies for responding locally to bleaching events by piloting certain methods and sharing experiences with the rest of the scientific and management community.

This module considers whether meaningful actions can be taken during and after mass bleaching events to reduce ecological impacts. While above-average sea temperatures are outside the control of reef managers, other factors that influence coral reef resilience to mass bleaching are amenable to management. Ecosystem condition, which influences coral survivorship during mass bleaching events and reef recovery after bleaching-related mortality, can be maintained and improved by effective management of local stressors. However, it is the physical conditions: temperature, light, and mixing, that principally determine whether corals bleach. They also play a key role in determining the probability of mortality during bleaching events. While these factors are not amenable to intervention in conventional management approaches, concern about the future of coral reefs is driving new thinking about ways in which bleaching risk might be mitigated.

Many of the strategies for management intervention during and following bleaching are based on emerging ideas that have yet to be fully tested. Some may turn out to be fruitful initiatives, especially those aimed at reducing local stressors; however, most should be considered experimental and undertaken in the spirit of adaptive management. The temperature anomalies that trigger coral bleaching events place substantial stress on coral colonies, even before there are any visible signs of bleaching. Once a coral is bleached, it is in a state of extreme stress, with reduced capacity for feeding and maintenance of essential physiological functions, such as injury repair and resistance to pathogens.

Ultraviolet light is known to be a key factor in coral bleaching, and small-scale experiments have shown that reducing intensities of UV light have reduced the incidence or severity of bleaching. These observations suggest that shading moderate sized areas during periods of greatest temperature stress may reduce the amount or severity of bleaching. However, practical considerations involved in implementing a shading strategy, as well as the potential for unwanted side effects, make this proposal particularly challenging. Small to medium-scale experimental tests of this strategy would be best accomplished through close science-management partnerships.

Although water temperatures are not amenable to management intervention at large spatial scales, there may be potential for temperatures to be manipulated in some localized circumstances. In situations where high water temperatures are due to the solar heating of shallow or contained water bodies, relatively small volumes of cool water may be adequate to maintain temperatures below critical bleaching thresholds for at least some species. Deep water adjacent to such sites may provide a readily available source of cool water. This strategy may become increasingly appealing at high use tourism sites should coral reefs continue to degrade because of temperature-induced stress. The feasibility of this idea has not been thoroughly investigated to date, and no field tests are known.

The amount of water exchange around a coral colony during thermal stress has been hypothesized to influence the severity of bleaching. Increased water flow is thought to increase the flushing of toxins that are the by-products of the cellular processes which lead to coral bleaching. Therefore, it is possible that increased flushing of toxins through greater water circulation around coral colonies may reduce the severity of bleaching or at least delay the onset of bleaching. If greater mixing could be achieved, it is likely that the amount of damage from a thermal stress event could be reduced. The role of water flow in determining the impacts of thermal stress on corals is still being studied, and the practicality of this strategy for management intervention has not yet been fully tested.

Snorkeling, diving, and boat anchoring are all activities that can cause physical injuries to corals if not carefully managed. A coral stressed due to bleaching is likely to be less capable of recovering from physical injuries due to these activities. Repair of even minor tissue damage may be hindered while the colony is in a stressed condition, increasing the risk of infection or overgrowth by competing organisms. Although the principles behind these theories are well established, there have not been any direct studies of the effect of bleaching on a coral’s response to physical injury. However, reef managers may wish to explore the costs and benefits of minimizing activities that could expose stressed corals to increased risk, especially in high-visitation tourism sites.

Degraded water quality affects various life stages of corals, making it likely that it exacerbates the effects of coral bleaching. Acute increases in sediment and pollutants deliver additional stress to corals that must clear sediment from colony surfaces, which wastes precious physiological resources. Corals stressed from mass bleaching are likely to be less effective at defending against invasion by microalgae or at competing with macro alga. Additionally, nutrient inputs can significantly reduce coral recovery. In light of these implications, managers may wish to consider the timing of coastal activities during periods of increased temperature stress. Limiting coastal activities during bleaching events could reduce the risk of damage to coral communities that could result from negative interactions between stressors such as turbidity and temperature. Such a strategy could also reduce the risk that developers will be held responsible for any bleaching mortality.

Herbivores play a critical role in facilitating recovery of coral reefs after major disturbances. In many locations, the grazing activity of herbivores is essential to the maintenance of substrate suitable for coral recruitment. For this reason, should a bleaching event result in substantial coral mortality, a reef manager may wish to consider short- to medium-term initiatives to protect the herbivore function. This is most relevant in countries where herbivorous fish populations are under threat from fishing pressure. These initiatives are most effective if they are done in partnership with relevant stakeholder groups. Ideally, restrictions would be maintained until significant recovery is evident or until there is other evidence that adequate settlement substrate can be maintained despite fishing pressures.

Ecological restoration is defined as the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed. Coral reef managers face a difficult role in determining to what extent we decided to implement intervention methods of enhancing recovery in natural reef ecosystems. However, with increasing degradation on coral reefs being witnessed globally we must consider whether taking an active part in reef restoration is a viable option. Considerations in taking these actions include: Is the action ethical? Is restoration the best use of MPA resources? Will it provide for the purported benefits, and can I afford the costs of monitoring to evaluate for success of the project(s)? What are the appropriate techniques for my region or reef type? Are the methods cost-effective, and can I identify partners to share the costs? What scientific issues and philosophical questions will be raised? Do I have the legal authority, and can these authorities be used for restoration activities in support of my MPA?

Restoration includes direct interventions such as transplantation, as well as indirect management measures to remove impediments to natural recovery. Interventions to improve habitat community structure and increase available space for recolonization by corals might include re-introductions, like sea urchin populations (e.g. *Diadema* in Florida). Coral transplantation, coral recruitment enhancement, and habitat modification are all methods of reducing the natural recovery time of damaged reefs. In the Florida Keys National Marine Sanctuary, on and offsite compensatory restoration projects are implemented to address human-induced impacts to natural resources by coastal construction or vessel grounding activities. Compensatory restoration decreases the time for recovery from anthropogenic impacts. Funds, generated through injury assessments on groundings or as mitigation for coastal development impacts, can be channeled into coral rescue, relocation, recovery and coral aquaculture programs.

On-the-Web

Restoration:

Mote Marine Lab: http://www.mote.org

Mote Magazine Articles on MML Coral Reef Research: *Science to the Rescue: Focusing on Coral's Future; Slime Sleuth*; *Coral Bleaching*; *Propagating Polyps; etc.*
http://www.mote.org/index.php?src=directory&view=magazine

Mote Marine Lab Microbiology Program:
http://isurus.mote.org/Keys/marine_microbiology.phtml

Coral Spawning: Deep Sea 3D IMAX http://www.imax.com/deepsea/
An IMAX film that includes stunning shots from 2005 coral spawning event at the Flower Garden Banks National Marine Sanctuary. **IMAX Corporation**, New York
Romi Schutzer: rschutzer@imax.com

TNC Community-based Staghorn and *Diadema* Restoration (Johnson/Nedimyer)
http://www.frrp.org/workshop/staghorn_restoration.pdf
http://www.nature.org/magazine/winter2006/misc/art20978.html?src=s2

The New York Times Planet Us: Coral Man video:
http://video.on.nytimes.com/?fr_story=fab4b739c612604ce3c6169cf41bccd4f0852815

Community-Based Restoration Partnerships:
http://www.nmfs.noaa.gov/habitat/restoration/projects_programs/crp/index.html

Florida Keys National Marine Sanctuary Coral Reef Restoration:
http://floridakeys.noaa.gov/resource_protection/grounding_restoration.html

NOAA DARP Homepage: http://www.darp.noaa.gov/

General:

The Nature Conservancy Florida Reef Resilience Program:
http://www.frrp.org/

The Florida Keys National Marine Sanctuary
http://www.floridakeys.noaa.gov/

Florida Keys National Marine Sanctuary Blue Star Program
http://www.sanctuaryfriends.org/whatwedo_bluestar.cfm

Mote Marine Lab BLEACHWATCH
www.mote.org/Keys/bleaching.phtml

Mote Marine Lab Marine Ecosystem Event Response & Assessment (MEERA)
www.mote.org/Keys/meera.phtml

Event Reports: www.mote.org/Keys

Publications and References

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Precht, William F. 2007. *Coral Reef Restoration Handbook.* Taylor & Francis Group, U.S.A.; 2006. 384 p. (ISBN 0849320739)
Contact: George Kenney, Taylor & Francis Group, 6000 Broken Sound Parkway NW, Boca Raton, FL 33487; Phone: 561-998-2544, Fax: 561-998-9784, george.kenney@taylorandfrancis.com

Causey, Billy D. Ph.D. 2007. **Climate Change: What Can Coral Reef Managers Do To Address Coral Bleaching?** Draft manuscript in review, (Clive Wilkinson). Florida Keys National Marine Sanctuary, 33 East Quay Road, Key West, FL 33040, USA. billy.causey@noaa.gov

Moe, Martin A., Jr. 2003. *Coral Reef Restoration: Returning the caretakers to the reef.* Sea Scope newsletter; Aquarium Systems, Inc.: Moorpark, CA, USA. Vol 20, Issue 4, 2003. (http://www.instantocean.com/sites/InstantOcean/knowledge/newsletter.aspx?id=1298)

Okamoto, Mineo; Satoshi Nojima, Yasuo Furushima and William C. Phoel. 2005. *A basic experiment of coral culture using sexual reproduction in the open sea.* Fisheries Science, 71:263-27

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.

Lessons Learned from the Intensification of Coral Bleaching from 1980-2000 in the Florida Keys, USA: 60-66 pp. Billy D. Causey, 33 East Quay Road, Key West, FL 33040, USA. billy.causey@noaa.gov

Wilkinson, C., Souter, D. (2008). *Status of Caribbean Coral Reefs after bleaching and hurricanes in 2005.* Global Coral Reef Monitoring Network, and Reef and Rainforest Research Centre, Townsville, 152 p. (ISSN 1447 6185)
Available for download from:
http://www.coris.noaa.gov/activities/caribbean_rpt/

www.gcrmn.org

Module 7: Communications

Section 1: Communicating Climate Change, Coral Bleaching, and Resilience

Learning Objectives

By the end of this module you will have:

- An understanding of why we need to communicate about the impacts of climate change to coral reef ecosystems.
- Identify different audience and think about how to tailor communication strategies to target each audience.
- Heard about innovative ways others are communicating to the public and stakeholders.

Background

Effective Management can mean so many different things. When you break it down to the bare issues, you discover that it is all about **People** and how they relate to their **Environment**. Instead of focusing on one particular approach to managing reefs effectively, this section focuses on the fundamental component to any effective management strategy: **COMMUNICATION**. Paying attention to how you communicate information and to whom is the first step to becoming more effective. Add to that some creative spark, and you might be on to something that advances your efforts substantially.

In this section, we want you to 'think outside the box' and work together to come up with a communication strategy that you can take home with you. We will tie together several of the previous sections to discuss the importance of communicating about mass bleaching and management strategies to various audiences. It is crucial to communicate the ecological and socioeconomic impacts of coral bleaching in order to raise awareness, impact decision makers, change behavior, and raise funds for future research. It is also important to realize that managing for resilience does not always look like traditional management, so communicating this will be very important. This brief module examines how to identify various audiences and how to tailor messages to each audience for maximum impact.

Mass coral bleaching is an issue that attracts strong interest from the public, the media, and policy/decision-makers and it is an issue we can take advantage of to communicate about the causes and impacts of climate change, resilience, management strategies, etc. In response, managers will want to provide up-to-date and informative answers to important questions about mass bleaching events and related impacts.

A communication strategy for responding to mass bleaching might have three aims:
(1) Gain support from supervisors and constituencies to respond to mass bleaching in the short and long term

(2) Engage stakeholders in a two-way communication about the extent and severity of bleaching and actions that can be taken to build reef resilience

(3) To work with the media to raise awareness of mass bleaching events and their impacts among the general public.

In working with any audience, managers are advised to take an approach that is clear and well thought out, proactive, solution-oriented, balanced, and respectful of political constraints. In communicating about mass bleaching, it is important that managers maintain the trust of their supervisors and the credibility of their reputation. Managers should be aware of political and social sensitivities and operate within organizational constraints. Managers also need to resist temptations to over-dramatize issues or events in order to meet the expectations of the press. This is of particular importance when bleaching is patchy and tourism operators are wary of the condition of their frequently visited sites becoming highlighted in the media. Lost credibility due to exaggeration of facts or presentation of premature conclusions can be costly and, sometimes, impossible to regain.

Worksheet or Activity

Worksheet: Communications in your Bleaching Response Plan.

Worksheet: Resilience Communication

Activity: Communications Campaign

COMMUNICATIONS STRATEGY

The following provides a briefing schedule to senior management, the governor or other elected official, the p
to be conveyed according to the risk or severity of bleaching. Fill in dates and triggers that are appropriate to
the message that should be conveyed in each of these cases. The Great Barrier Reef Marine Park Authority
provided on the back of this sheet as an example.

		Briefings				
Approx. date (adjust per your site)	Trigger[1]	Senior Management	Elected official	Stakeholders and partners	The media	Examples of messages (t
1 June						Summer approaching; bleachi prepared
	High bleaching risk					Temperatures unusually high; probable
	Moderate bleaching					High temperatures recorded; observed; areas worst affected
	Severe bleaching					Very high temperatures record observed; areas worst affected
15 July						Temperature trends for first hal reports of coral bleaching
15 September	No bleaching					Summer concluding; bleaching significant bleaching observed
	Moderate or severe bleaching					High water temperatures recor bleaching observed; prelimina and severity; detailed surveys
15 October	Moderate or severe bleaching					Summary of full extent and sev implications for the reef
Monthly						Updates on temperature trends publish to web and email to all

EXAMPLE: **GREAT BARRIER REEF MARINE PARK AUTHORITY COMMUNICATIONS STRATEGY**

		Briefings			
Approx. date	Trigger[1]	Senior Management	Minister	Stakeholders	Message
1 Dec		^	^	^	Summer approaching; bleaching risk period; GBRMPA prepared
20 Dec		^			Temperature trends for December; plans for Christmas break
	High bleaching risk	^	^		Temperatures unusually high; coral bleaching event probable
	Moderate bleaching	^	^	^	High temperatures recorded; moderate bleaching observed; areas worst affected
	Severe bleaching[2]	^	^	^	Very high temperatures recorded; severe bleaching observed; areas worst affected; mortality likely
15 Feb[3]		^			Temperature trends for first half of summer; summary of reports of coral bleaching
31 March	No bleaching	^	^	^	Summer concluding; bleaching risk period over; no significant bleaching observed
	Moderate or severe bleaching	^	^	^	High water temperatures recorded during summer; bleaching observed; preliminary assessment of extent and severity; detailed surveys underway
31 April	Moderate or severe bleaching	^	^	^	Summary of full extent and severity of bleaching; implications for Great Barrier Reef
Monthly[4]		^			Updates on temperature trends and coral condition; also publish to web and email to all staff

Resilience Communication Worksheet

Instructions: In this exercise, you are going to begin to develop a communication plan that is specific to Resilience that will assist you in your management strategies. Your main message or theme can be delivered in a variety of ways including advertising campaigns, school programs, radio show, a video – the possibilities are endless. The most important thing is to make sure it is focused and outcome oriented. Follow the steps in the Resilience Communication Worksheet to complete this exercise.

OUTPUT: Communication campaign plan outlined

Try This At Home: To have a well developed effective communication campaign, it requires a dedicated staff person to make sure it is implemented. Working with community volunteers and available resources can produce a great product that gets attention.

Step 1. What is your goal for your communication strategy? (see examples below)

GOAL: ____

____

____

Examples of types of goals:
To raise awareness
To increase cooperation or compliance
To gain political support
To get young people involved
To change behaviors of resource users

Step 2. Identify Resilience issue of concern (see helpful questions below)

Resilience Issue of Concern: ____

____

____

??Helpful Questions??

1. What aspect of the resilience principles would resonate most with your target audience?
2. Does your issue of concern have a practical application?

3. Does it have an emotional element that people would respond to?

Step 3. Identify your target audience and secondary audiences for your communication plan* (See helpful questions below)

**Note that the audience refers to the group you are trying to influence. You will be able to identify groups that can HELP you with this later in the exercise.*

??Helpful Questions??

1. Who is your primary audience?
2. What other audiences might be interested or relate to this message?
3. Which audiences have the most political influence?
4. Which audiences have the most social influence?
5. Who will be most positively affected by any management actions?
6. Who has the potential to be negatively affected by any management actions?
7. Who will be involved in the implementation of management actions?
8. Who usually causes confusion or trouble when information is distributed to the public or your key audience?

Please fill out this table

Primary Audience	Description	Rationale

Please fill out this table

Secondary Audience	Description	Rationale

Step 4. Identify and rank most effective methods of communication or message delivery (see helpful questions below)

??Helpful Questions??

1. How do people usually get information where you live? (TV, radio, newspaper, friends, religious gatherings, local shop, village meetings, etc.)
2. Which medium seems to be most powerful or influential?
3. Do people respond to visual images?
4. Are people interested in local politics and decisions?
5. Do people read the news regularly?

For Ranking:

6. What is the least expensive way to communicate with people?
7. Do you have existing resources or education programs that you could build on?
8. Are there specific education or outreach campaigns/programs that you can expand?
9. Are there resources in your community to help you implement your plan/strategy?

Please fill out this table

Method of Communication	Feasibility Ranking (1-5) 5 = most feasible	Notes

Step 4. Identify who should have primary responsibility for implementation

Person/Agency Responsible:____

____

Step 5. Identify individuals, organized groups, or institutions that can help or support implementation

Helper	Description of Potential Contribution

Step 6. Identify resources available to you currently (see helpful questions below)

Staff	Schools	Events	Other
e.g. Public Relations Specialist	e.g. Ocean studies course	e.g. National Holiday Celebration	

??Helpful Questions??

1. Are there existing outreach or communication programs in your area or for your site?
2. Are there school programs that have environment or ocean classroom modules in place?

3. Are there particular teachers in your community with an interest in developing such programs?
4. Do you have TV or radio shows that highlight or discuss local issues?
5. Are there annual events that most of the community participates in? (e.g., agriculture exhibits, weekly markets, social events, religious events)

Step 7. Identify additional needs for you or your organization to successfully implement this plan/strategy

Potential Needs	Yes/No	Notes
Funding		
Expertise		
Materials		
Other		

Step 8. Layout a preliminary timeline for activity or program implementation

Timeframe (by quarter)	Activity Description	Milestones	Outcomes
Example: 1st Quarter	Conduct community survey on current perceptions about status of reefs	1. Develop survey; 2. Implement survey; 3. Analyze survey	Report on current perceptions to be used to shape message or info distributed

Activity – Not Using this Activity in Guam

Application Exercise: Communication Campaign

Goal: To develop a communication campaign that is appropriate for your problem and place

Guidelines: In this exercise, you are going to begin to develop a communication campaign that is specific to the issues of resilience, climate change, or bleaching that will assist you in your management strategies. Your main message or theme can be delivered in a variety of ways including advertising campaigns, school programs, a radio show, a puppet show, a video, a song for radio – the possibilities are endless. The most important thing is to make sure it is focused and outcome oriented.

Group Exercise
Instructions:

1. Identify issue or message
2. Identify communication goal
3. Identify key/target audiences
4. Identify best method of delivery (skit! song & dance!)
5. Identify concerns/emotions of stakeholders
6. Develop campaign that is audience appropriate
7. Pitch it to us

Output: Communication campaign framework developed

Try This At Home: To have a well developed effective communication campaign, it requires a dedicated staff person to make sure it is implemented. Working with community volunteers and available resources can produce a great product that gets positive attention.

On-the-Web

Great Barrier Reef Marine Park Authority Education Unit: http://www.reefed.edu.au/

The Nature Conservancy Reef Resiliency Toolkit: *www.reefresilience.org*

The Reef Environmental Education Foundation: http://www.reef.org/

Coral Reef Alliance-International Coral Reef Information Network Library
www.coralreefalliance.org

ReefBase: www.reefbase.org

NOAA’s Coral Reef Conservation Program – Outreach and Education Program
http://www.coralreef.noaa.gov/outreach/welcome.html

Florida Keys National Marine Sanctuary Website:
http://www.fknms.nos.noaa.gov/edu/welcome.html

Module 8 Introduction to the Bleaching/Crisis Response Plan

Section 1: Developing a Bleaching/Crisis Response Plan

Learning Objectives

In this module you will be developing bleaching response plans for your reef that will enable you to:

- Predict Mass Bleaching
- Set thresholds for declaring mass bleaching
- Assess the ecological impacts of mass bleaching
- Assess the socioeconomic impacts of mass bleaching
- Communication about mass bleaching before, during, and after the event
- Implement management interventions to increase coral survival during events
- Fund activities called for in the plan
- Staff activities called for in the plan
- Gain support for the plan you have developed

Background

In order to respond effectively and quickly to mass bleaching events and the impacts of climate change, managers need a plan. At its most basic level, the plan should identify the goal of the response, specific steps that will be taken to meet the goal, and resources required to implement the response. Plans should also take into account available resources, staff capacity, management authority, and the characteristics of local reef systems. The Great Barrier Reef Marine Park Authority (GBRMPA) Bleaching Response Plan provides a good example. The plan includes procedures for prediction, ecological assessment, and communication of mass bleaching impacts.

Routine tasks occur throughout the summer, whether or not there is bleaching. For example, routine tasks include monitoring environmental conditions and frequently assessing the bleaching risk. Responsive tasks are only implemented if a bleaching event occurs. Responsive tasks include rapid assessment of ecological impacts and increased communication with senior managers and the media. Because it can be difficult to decide exactly when a bleaching event has started, the GBRMPA plan outlines specific thresholds that trigger each type of responsive task. For example, when bleaching thresholds are exceeded at multiple sites, an aerial survey is undertaken to determine the extent and severity of bleaching. Strategic tasks may be taken at any time to strengthen a bleaching response or support long-term coral reef resilience. Strategic activities can include: building capacity, securing funding, raising awareness, developing professional networks to exchange information, establishing policies that support bleaching response, or protecting/restoring factors that confer resilience to the system.

Activity

Activity 5: Developing a Bleaching Response Plan

Developing Bleaching/Crisis Response Plans

Develop a bleaching response plan for a coral reef area under your management (*i.e.*, the area managed by one group member). You may use the GBRMPA bleaching response plan as a model or create an entirely new approach. Use the worksheets that you have been filling out through out the workshop to help you with the different components of the plan.

- *Work in groups of approximately four people*
- *Use flipcharts*
- *You have a set amount of time to develop the plan*
- *You will be reporting back to the main group at the end of the exercise*

Think about how you will:

- Predict mass bleaching events
- Setting thresholds for declaring mass bleaching
- Assess the ecological impacts of mass bleaching
- Assess the socio-economic impacts of mass bleaching
- Communicate about mass bleaching before, during and after the event
- Implement management interventions to increase coral survival during events
- Fund activities called for in the plan
- Staff activities called for in the plan
- Gain support for the plan

Sharing Bleaching/Crisis Response Plans

In this exercise, you will share your bleaching response plans that you have developed with the rest of the workshop group.

On-the-Web

Great Barrier Reef Marine Park Authority Bleaching Response Plan:

http://www.gbrmpa.gov.au/corp_site/info_services/science/climate_change/management_responses/coral_bleaching_response_plan

Publications and References

Maynard, J.A., J.E. Johnson, P.A. Marshall, C.M. Eakin, G. Goby, H. Schuttenberg, and C.M. Spillman. A Strategic Framework for Responding to Coral Bleaching Events in a Changing Climate. *Environmental Management* DOI 10.1007/s00267-009-9295-7.

Woodley, C.M., Bruckner, A.W., McLenon, A.L., Higgins, J.L., Galloway, S.B. and Nicholson, J.H. 2008. *Field Manual for Investigating Coral Disease Outbreaks*. NOAA Technical Memorandum NOS NCCOS 80 and CRCP 6. National Oceanic and Atmospheric Administration, Silver Spring, MD 85pp.

Slides

  - Field Exercise Worksheets – Evaluating Reef Resilience
  - BleachWatch Field Sheet
  - Hawaii Eyes on the Reef

Activity 1: You Make the Call

Goal: To integrate various information from different sources and at different temporal and spatial scales to determine the risk of bleaching at your reef.

Purpose: The purpose of the "You Make the Call" exercise is to integrate information from many different sources to determine if the reef you are managing is at risk for bleaching. The exercise spans three weeks, and participants will consider how changing weather, sea surface temperature, and local conditions might change the threat of bleaching.

Instructions: Instructor will divide participants up into four groups based on their location in the room. Your group will receive a piece of paper with a type of reef and basic information about the reef. The information will include:

- Reef type
- Tidal range
- Important information about adjacent landscape features, uses, etc.
- Current Conditions
    - Recent Weather
    - Satellite Bleaching Alert Status
    - Bleaching Observations
    - Other Relevant Events

Based on current conditions for this first week including recent weather, satellite bleaching alert status, bleaching observations and other events you will be asked to determine how great a threat your reef is for widespread coral bleaching. Once the threat level is determined for week 1, updated information for week 2 and then week 3 will be passed out. Based on changes in weather, satellite bleaching alert status, etc. participants will be asked to revise their threat level over time.

Activity 2a: MPA Reef Classification

Goal: To develop a classification map of the major reefs types and zones for your region

Purpose: The reef classification map will be used in the next exercise to identify representative and resilient reefs and replicates for selection as MPAs/zones. It can also be used to develop the sampling design for a rapid response plan for a major coral bleaching.

Instructions:

1. Delineate major reef types (e.g., atolls, barrier, fringing, patch) and zones (e.g., fore reef, back reef, spur and groove) on your map
2. Identify three factors that explain major coarse divisions in coral reef communities across your region (e.g., wave energy, ocean circulation, isolation)
3. Identify three factors that explain finer level differences (e.g., depth, salinity, turbidity)
4. Apply these factors to differentiate among the reef types and zones on your map
5. Draw divisions on your map and note the reasons.

This should be done using maps provided (or that you brought with you). Use markers to draw boundaries, make notes, or highlight special features on your map. Record your decision-making process in the notes section so that you may return to this activity in the future.

OUTPUT: Country map with reef areas classified

Activity 2b: MPA Design and Zoning

Goal: To design a network and zoning scheme of your MPA.

Purpose: Using information developed in the reef classification exercise, identify representative and resilient reefs and replicates for selection for MPAs/zoning schematic. This preliminary work can be used to begin the process of designation or consideration of zones in existing managed areas with stakeholders at your site(s).

Instructions:
Based on the information you developed in the classification exercise and the criteria listed below, choose a portfolio of MPA sites for your country or zoning scheme for your site. This should be done using maps provided (or that you brought with you). Use markers to draw boundaries, make notes, or highlight special features on your map. Record your decision-making process in the notes section so that you may return to this activity in the future.

Step 1: Review criteria below to further describe your area
- Good example of reef or habitat type
- Good condition
- High biodiversity
- Low level of threat
- Survived bleaching
- Recovering well from bleaching mortality or disturbance
- High habitat complexity
- Replicates of the above at regular intervals (20 km where possible) by Latitude/Longitude

Step 2: Identify Critical Areas

Step 3: Choose a portfolio of MPA sites for your country or zoning scheme for your site using what you've learned about resilience and rules of thumbs for connectivity, critical areas, size, shape, spacing, and socioeconomic criteria

Step 4: Peer review your work within your group (if more than one country)– prepare to report back in a 30 minute poster session at end of exercise

OUTPUT: Country map with MPA or MPA network design/zoning scheme

Rules of Thumb Checklist for MPA/Network Design

Representation & Replication

- Good representation of habitat types, structure, function, physical conditions
- Minimum of 3 replicates of each habitat type/condition (classified area)

Critical Areas

- Inclusion of important nesting, breeding, and nursery grounds
- Inclusion of special areas (e.g., likely resilience/resistance to bleaching, ecologically sensitive areas)

Connectivity

- Inclusion of known 'source' areas
- Protection of habitat linkages (e.g., reef to seagrass to mangrove)

Size, Spacing, Shape

- 10-20 km diameter at minimum width
- Fewer large better than many small
- 10-20 km between core zones or MPAs
- Regular shapes easy to delineate and enforce (e.g., squares, rectangles, straight lines)

Socioeconomics

- Consider locations away from industrial areas or other high impact land use areas
- Consider existing activities that may be impacted or have negative impact on MPA (e.g., traditional use, commercial use, recreational use)
- Consider user conflicts to minimize future problems

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Building Resilience into MPA Network Design[1]

Reef Resilience Principle: Representation, replication, and risk-spreading – This important step helps to address the uncertainty managers face because of the incomplete knowledge of resilience science. This step calls for managers to protect multiple examples of the full range of coral habitat types, including critical habitats of target species. Replication of each habitat type at multiple locations reduces the risk of any one type being totally lost during a major bleaching event or hurricane, for example. So, if any one coral community is lost, others remain to provide necessary larvae and help it to recover.

Design Principles	Action
For larger areas (scale of 100s-1000s km), Conserve representative examples of each bioregion (i.e., biologically distinct ecosystem). For smaller areas (scale 10s of km or less) select reef types and the major reef zones that are found on atolls and barrier reefs to serve as proxies for community types. Include a "sufficient" number and area of each bioregion or reef type and major reef zone, and spread them out geographically (e.g., at different latitudes) to reduce the chances that they will all be negatively impacted at the same time. Aim to include a least 30% of the area of each target ecosystem where feasible. Where information is available, include a minimum amount (see above) of each ecosystem and community type within each bioregion (to ensure that all known communities and habitats are protected). Choose representative areas based on knowledge (high biodiversity areas, complementarity) to maximize the number of species protected.	Classify and map reef types and major reef zones or other distinct community types, and categorize these by their functional groups and biodiversity. Based on the results of field surveys where these exist or in combination with expert knowledge, include the following: • Coral reef types categorized by location, including reef type and position relative to the shore (e.g., inshore fringing reefs, mid-shelf patch reefs, barrier reef, atoll) and degree of exposure to wave energy • Seagrasses • Mangroves • Relevant deepwater habitats. Determine community structure and biodiversity of each category of the classification and use this information to further differentiate between representative types of each category. Select and protect multiple examples of the full range of coral community types with their associated habitats.

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[1] Sources: TNC Resilience Model; Building Resilience into MPA Design: Kimbe Bay, PNG (TNC-Lokani and Green); Salm, Done and McLeod ….

Reef Resilience Principle: Protect refugia and other critical habitats – It is also important to protect communities that are naturally positioned to survive global threats. These refuges provide secure and essential sources of larvae to enhance the replenishment and recovery of reefs damaged by bleaching, hurricanes, or other events.

Design Principles	**Actions**
Choose sites that are more likely to be resistant or resilient to global environmental change. In particular, include areas that: • may be naturally more resistant or resilient to coral bleaching; • include critical habitats for key species; • support high species diversity; • contain a variety of habitat types in close proximity to each other.	Identify and map the location of resistant reefs that avoid or survive bleaching and resilient reefs that recover quickly and well from bleaching events. Select and protect examples of both resistant and resilient reefs. Map the location of critical habitats of key target species, including spawning aggregations (permanent or transient) and nursery, developmental and feeding habitats, and migration corridors of: • larger groupers, snappers, and other key species targeted by fisheries • sea turtles • cetaceans • species with limited distribution and abundance • vulnerable species (e.g., sharks, and those on the IUCN red list) Where data, funds and expertise are available, develop hydrodynamic models to help identify areas of mixing of deep cool water with heated surface water to help identify bleaching resistant areas If high technology solutions are not in reach: • summarize best available information on past events based on local knowledge and field observations • design rapid response protocol to enable a major bleaching event to be tracked, the impact measured, and observations compared to high resolution (1 km) sea surface temperature maps. From data gathered through field surveys or expert knowledge, identify coral communities with broad size frequency distributions, including small, intermediate and large size classes. Small/young and intermediate sizes indicate strong regular recruitment. Larger colonies indicate natural long-term survival of catastrophic events. These are important indicators of resistance/resilience. A high ratio of live to dead coral is also a good indicator of resilience.

Reef Resilience Principle: Effective management – Effective management is at the core of resilience. Managers need to protect reefs from direct threats such as pollution, sedimentation, and destructive fishing (including overfishing) and keep them healthy. The healthier the reefs, the more resilient the corals are, the greater the chance of successful recruitment, and the more likely they will be to bounce back after a catastrophic event.

Design Principles	Actions
Strong government and community support for MPAs and a collaborative approach to MPA management will help to reduce management challenges. Consider sea and land use, particularly proximity to threats and other protected areas and impacts on water quality. Consider if the distribution and status of biological community types are the result of natural processes or human impacts – the community state may not be natural and may not be reversible, perhaps requiring this to be a lower priority sites for conservation. Recognizing that MPAs and MPA networks cannot address all threats to target ecosystems, particularly those originating from outside MPA boundaries (e.g., runoff from land use practices), for management to be effective, every effort should be made to embed these in broader management frameworks, such as integrated coastal zone management or large multiple use zoning plans. Consider management of functional groups (e.g., reef builders, predators, herbivores) within reefs and of linkages among reefs and associated habitats (e.g., seagrasses, mangroves, and adjacent deep water habitats) as a means to achieve an ecosystem based focus to management. Conserve rare and threatened species (e.g., cetaceans,	Establish partnerships with concerned agencies to enable collaboration across resource management sectors (fisheries, conservation, rural development, land use, water use, agriculture, urban development, etc. as appropriate) and integration of coral reef conservation into broader policy and management frameworks. Regularly meet and consult with local government and community leaders over management issues and strategies and seek joint solutions to resolve major issues, including the development of alternative livelihoods for affected community members where feasible. Determine the levels of use of coral reefs for different purposes and the degree of dependence of local communities on these resource uses – use the information to direct management effort toward those sectors of the communities that are most dependent on coral reefs and collaboratively seek solutions to resolve issues and abate threats. Determine the distribution and extent of local human impacts through: • land use patterns and their downstream impacts on coral reef systems; • direct resource use (particularly fishing) – use this information to direct management effort to control the impacts of damaging uses. Embed a series of no-take zones in the MPA as a means to build populations and achieve balance between different functional groups, such as predator and herbivore fishes. Prohibit all forms of extractive use and control visitor access in the protected, bleaching resistant refugia sites. Manage for good water quality by addressing sources of pollution that create conditions which favor algal growth and prevent coral larvae from settling. Commission research into the role and correct balance of functional groups to inform

dugongs/manatees, sea turtles, seabirds, sharks, and crocodiles). Emerging global threats, like climate related coral bleaching with all of its unknowns, require an adaptive approach to management.	management strategies. In the absence of information on functional groups, consider mass removal of coral predators (e.g., crown-of-thorns starfishes and predatory mollusks) from reefs that are recovering from bleaching or other major events and manage fisheries to maintain herbivores at levels that effectively reduce algal competition with coral larval settlement. Map out the information from dedicated surveys or expert/local knowledge on the distribution and abundance of rare, threatened or vulnerable species (and their critical habitats) and include these in specially protected zones. Design MPA and zone boundaries to be flexible in space and time so that these can be expanded or contracted, have seasonal or other fixed time limits, be moved to different levels of protection, and so be made to be more responsive to changing conditions. Tailor monitoring programs to address issues of bleaching resistance, determine connectivity patterns, and accommodate rapid response to bleaching events. A rapid response mechanism allows managers to engage local users to help track the bleaching impact and to measure and interpret the response in light of different factors that might explain the different levels of mortality and recovery.

Reef Resilience Principle: Incorporate connectivity – Some reefs may be sufficiently large to be self-seeding. Others may rely on reefs up current to provide the larvae they need for replenishment. Understanding how and where the larvae of corals and other reef species are distributed enables managers to identify source and sink reefs and to link these into a network of protected areas that is mutually replenishing. In this way, coral habitats that are damaged by bleaching or other causes can be repopulated by larvae from healthy reefs that are positioned up current.

Design Principles	Actions
Take a system wide approach that recognizes patterns of connectivity within and among ecosystems (including linkages among coral reefs, seagrasses, mangroves, watersheds, etc.) Where possible, include the entire ecological units (e.g., whole reefs together with their associated seagrass beds and mangroves), including a buffer around the core area of interest. Where entire biological units cannot be included, choose larger over smaller areas to accommodate self-seeding. Maximize acquisition and use of environmental information to determine the best configuration, recognizing the importance of connectivity in network design. In the absence of good info on connectivity, use strategy of representation, replication, and risk spreading as an interim measure or proxy for connectivity (example reefs need to be close enough to have connectivity).	Attempt to learn about connectivity through dedicated studies of both biological and physical processes. Implement a desktop study of best available information on currents and bathymetry to provide patterns of physical connectivity. If resources permit, develop a hydrodynamic model to indicate likely patterns of connectivity. Use best available information from above steps to design or commission specific studies and seek expert knowledge to determine biological connectivity patterns.

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Activity 3: Selecting Socioeconomic Indicators

Goal: Define socioeconomic assessment objectives and select relevant socioeconomic indicators for a given scenario.

Purpose: To think about socioeconomic assessment objectives and select relevant socioeconomic indicators given a scenario of a community experiencing the impacts of climate change.

Instructions:

Given scenario: A coastal community of 10,000 people experiencing the following impacts:

- Climate: Rising sea surface temperature
- Biological impacts: Mass coral bleaching, coral mortality, decreasing abundance and availability of fish stocks
- Physical impacts: Weaken reef structure, more exposure for coastal erosion during storm surge events

Your tasks:

1. Define your socioeconomic assessment objectives:

2. From the examples of socioeconomic indicators presented in the Powerpoint presentation, select ones that are relevant and appropriate for the above objectives. Propose a data collecting method for each of the selected indicators. The methods include secondary sources, household survey, key informant interview, focus group discussion, and observation.

Activity 4: Field Trip – Evaluating Reef Resilience

Goal: To begin learning about one methodology for measuring reef resilience.

Purpose: This type of monitoring will help managers have a good idea which reefs are more or less vulnerable to bleaching. There are several advantages to having this information:

- Help target bleaching surveys
- Vulnerable areas may need more protection during & after bleaching
- Proactive steps might be taken to improve the resilience of vulnerable areas, so they would have a better chance of surviving a bleaching event
- Highly-resilient “refuge” areas may be good candidates for MPA protection

Instructions: Visit two field sites (reefs) that have two levels of resilience. Participants will complete one resilience worksheet per site. While still in the boat/on the beach, evaluate the above water resilience data. Once in the water, snorkel the reef area and evaluate the below water resilience data. Participants should discuss and compare their data once back on the boat or at the dock. Participants can also work through one of the community-based monitoring protocols (Coral Watch, Eyes on the Reef, etc.)

Materials:

- Snorkel gear
- Plastic Clipboards (1 per team)
- Resilience Worksheets (1 per site per team)
- Community-based monitoring protocol (optional)

OUTPUT: Completed field forms that compare two sites, and predict which will be more resilient to bleaching.

Activity 5: Drafting Your Bleaching Integrated Response Plan

Goal: To begin drafting a bleaching response plan for the participants' area.

Purpose: Pre-planning before a bleaching event allows managers to quickly respond when bleaching happens. It is critical to plan ahead for staffing, funding, communications, monitoring, etc. Having a plan in place should also help managers to gain credibility and political support with reef users and decision-makers.

Instructions: Develop a bleaching response plan for a coral reef area under your management (*i.e.*, the area managed by one group member). You may use the GBRMPA bleaching response plan as a model or create an entirely new approach. After the exercise you will have approximately 5-7 minutes to report back to the entire group your approach.

Materials:

- Flip charts (self-propping ones are easier to use)
- Colored markers
- Worksheets

Think about how you will:

- Predict mass bleaching events
- Set thresholds for declaring mass bleaching
- Assess the ecological impacts of mass bleaching
- Monitor pre-and post-bleaching to identify resilient reef areas
- Assess the socio-economic impacts of mass bleaching
- Communicate about mass bleaching before, during and after the event
- Implement management interventions to increase coral survival during events
- Fund activities called for in the plan
- Staff activities called for in the plan
- Gain support for the plan
- Will your plan address more than bleaching (disease outbreaks, crown-of-thorns, invasive species, storm events, etc.)? If so the same sort of questions as above should be considered for each event.

<u>Record your decision-making process</u> in the notes section so that you can return to this activity in the future. Refer back to the worksheets that you have filled out throughout the workshop to help you through the activity (Monitoring and Reporting Bleaching Conditions, Socioeconomic Considerations, Communication Strategies).

OUTPUT: Draft Bleaching/Crisis Response Plan

**If a current Rapid or Integrated Response Plan exists, revisit your plan and consider opportunities to integrate information you learned in the workshop to update the plan.

Guiding Questions:

1. Early Warning System:
    a. How often should NOAA satellite products be checked?
    b. Are there Virtual Stations close by, and are you signed up for e-mail alerts?
    c. Are there volunteers, dive operators, etc. who could be organized for a citizen monitoring system? What about pilots who fly over the reef regularly?
2. Assessment and Monitoring
    a. Can you do monitoring to try to identify resilient sites ahead of time?
    b. Who will be responsible for monitoring the extent & severity of bleaching?
    c. How will the extra monitoring be paid for, or can it be part of regular summer surveys?
3. Communications
    a. How to do pro-active communications before bleaching occurs—briefing decision-makers, press, etc.—so these groups will be on board if bleaching does happen. Any creative ideas on this from the communications/skit activity?
    b. What audiences should be contacted at the beginning of the bleaching season?
    c. What audiences should be contacted if bleaching does occur?
4. Routine Tasks during the bleaching season
    a. Who will be responsible for keeping an eye on the early warning system?
    b. Who to communicate with?
    c. What would trigger a shift to active bleaching response?
5. Responsive tasks if bleaching does occur
    a. Who will coordinate and carry out monitoring?
    b. Who to communicate with?
    c. Are there resources for follow-up surveys to assess mortality, months after the bleaching event?
    d. Who will analyze the monitoring data to look for resilient areas or places that are more vulnerable to bleaching?

Example Bleaching Response Plan Template

Adapted from the Great Barrier Reef Marine Park Authority Bleaching Response Plan

1. INTRODUCTION
2. PLAN OVERVIEW
  2.1 OBJECTIVES OF THE RESPONSE PLAN
3. EARLY WARNING SYSTEM
  3.1 CLIMATE MONITORING
  3.2 SEA TEMPERATURE MONITORING
  3.3 Eyes on the Reef
4. BLEACHING ASSESSMENT AND MONITORING COMPONENT
  4.1 SITE INSPECTIONS
  4.2 BROAD-SCALE SYNOPTIC SURVEYS
  4.3 INTENSIVE IN-WATER SURVEYS
  4.3.1 Temporal scale
  4.3.2 Spatial scale and survey sites
  4.3.3 Design and data analysis
  4.3.5 Complementary studies
5. COMMUNICATION STRATEGY
6. SOCIOECONOMIC IMPACTS
7. IMPLEMENTATION
  7.1 RESPONSE SCHEDULE
  7.1.1 Routine tasks
  7.1.2 Responsive tasks
  7.2 REPORTING AND BRIEFING SCHEDULES
  7.3 DEFINITION OF TRIGGERS FOR IMPLEMENTATION PLAN
8. MANAGEMENT INTERVENTIONS
9. FUNDING AND SUPPORT FOR BLEACHING RESPONSE
  [address capacity issues here]
10. REFERENCES
11. APPENDICES (include as appropriate)

Possible Appendices
APPENDIX A — Community Monitoring Reporting Form
APPENDIX B — Intensive Site Surveys
APPENDIX C — Rapid Assessment Survey Data Sheet
APPENDIX D — Codes for Intensive Surveys
APPENDIX E — Schematic Representation of Percent Cover

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MONITORING AND REPORTING BLEACHING CONDITIONS

The activities in the right-hand column are examples of activities related to monitoring and reporting bleaching c
these as is appropriate for your site. It is important to identify these activities and who will be responsible for con
back-up who is not likely to be on travel or vacation at the same time as the primary person. Determine the timi
Great Barrier Reef Marine Park Authority table of activities is provided on the back of this sheet as an example.

Frequency (e.g. weekly)	Timing (e.g. every Monday)	Person Responsible (also provide back-up)	Activity (modify and fill in other activities as needed)
Routine tasks:			
			Check the NOAA Seasonal Bleaching Outlook
			Check NOAA HotSpot & DHW maps on web
			Receive and review Coral Reef Watch Satellite Bleaching Alert u
			Review weekly weather summary (e.g., air temp, cloud cover an
			Review Coral Reef Watch reports and update maps
			Make use of traditional Hawaiian seasonal prediction tools
			Brief senior management team on weather and heating conditio
			(optional: if you publish bleaching conditions on your website): and coral conditions and draft bleaching risk current conditions r recent images. Announce web update and send brief report.
			Monitor extent of bleaching using existing information channels a
			Advise senior management if dramatic worsening of conditions i
			Others:
Responsive tasks:			
			Actively solicit confirmatory bleaching reports from reliable sourc monitoring participants, field scientists, tourist/dive operators, etc
			Alert relevant project coordinators and managers
			Brief senior management
			Brief elected officials
			Prepare media position, draft statement and consult with media
			Brief all staff, stakeholders and collaborators
			Release media statement
			Actively promote and solicit submissions to online bleaching rep spatial coverage
			Implement Bleaching Assessment and Monitoring component
			Others:

MONITORING AND REPORTING BLEACHING CONDITIONS

EXAMPLE: From GBRMPA Bleaching Response Plan

Frequency	Timing	Person Responsible (back-up)	Activity
weekly	Monday		Check GBRMPA ReefTemp and NOAA HotSpot maps on web
			Receive updated Great Barrier Reef sea temperature graphs from AIMS
			Review weekly weather summary, for example air temp, cloud cover and wind from Bureau of Meteorology
			Review BleachWatch (including BleachWatch Aerial) reports and update maps
			Print out ReefTemp and NOAA HotSpot maps for GBRMPA Climate Change Group Director to brief senior management team
Weekly/ fortnightly	Tuesday		Summarise weather, sea and coral conditions and draft bleaching risk current conditions report for website. Include recent images.
Weekly/ fortnightly	Wednesday		Have updated current conditions report reviewed, approved and published on external web
			Announce web update and send brief report
Weekly/ fortnightly	Constant		Monitor extent of bleaching using existing information channels and evaluate for trends (ie change in bleaching extent)
			Advise GBRMPA senior management team and the Minister for the Environment, Heritage and the Arts if dramatic worsening of conditions is evident
Event-based	High bleaching risk		Actively solicit confirmatory bleaching reports from reliable sources, including BleachWatch participants, Day-to-Day Management field officers, AIMS, other researchers, etc.
			Alert relevant project coordinators and managers
			Brief GBRMPA senior management team
Event-based	Moderate bleaching event detected		Brief GBRMPA executive and the Minister for the Environment, Heritage and the Arts
			Prepare media position, draft statement and consult with GBRMPA media coordinator and executive
			Brief all GBRMPA staff, stakeholders and collaborators
			Release media statement
			Actively promote and solicit submissions to online bleaching reports to provide wide spatial coverage
			Implement Bleaching Assessment and Monitoring component

SOCIOECONOMIC CONSIDERATIONS

It is important to consider the impacts to human users of coral reefs from climate change and coral bleaching. These will have both direct impacts, from the bleaching itself, especially when there is coral mortality, and indirect impacts from management measures intended.

Use this table to identify populations who may be affected by major coral bleaching events. These impacts will be important to report to the media and to elected officials. It is also important to understand up front the economic impacts of certain management measures (e.g. dredging bans during bleaching events).

Type of event	Populations who may be affected by bleaching (e.g. dive operators, fishermen)	Type of impact (social, cultural, economic)	Actions that may lessen impacts (examples: pre-bleaching warnings, economic mitigation, etc)
Direct impacts			
Moderate bleaching	1.		
	2.		
	3.		
Severe bleaching	1.		
	2.		
	3.		
Post-bleaching coral mortality	1.		
	2.		
	3.		
Indirect impacts			
Fishing restrictions	1.		
	2.		
Recreational use restrictions	1.		
	2.		
Restrictions on coastal development/ dredging	1.		
	2.		
Other:			

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COMMUNICATIONS STRATEGY

The following provides a briefing schedule to senior management, the governor or other elected official, the press and the message to be conveyed according to the risk or severity of bleaching. Fill in dates and triggers that are appropriate to your site. Think about the message that should be conveyed in each of these cases. The Great Barrier Reef Marine Park Authority table of activities is provided on the back of this sheet as an example.

		Briefings				
Approx. date (adjust per your site)	Trigger[1]	Senior Management	Elected official	Stakeholders and partners	The media	Examples of messages (tailor to your own site):
1 June						Summer approaching; bleaching risk period; we are prepared
	High bleaching risk					Temperatures unusually high; coral bleaching event probable
	Moderate bleaching					High temperatures recorded; moderate bleaching observed; areas worst affected
	Severe bleaching					Very high temperatures recorded; severe bleaching observed; areas worst affected; mortality likely
15 July						Temperature trends for first half of summer; summary of reports of coral bleaching
15 September	No bleaching					Summer concluding; bleaching risk period over; no significant bleaching observed
	Moderate or severe bleaching					High water temperatures recorded during summer; bleaching observed; preliminary assessment of extent and severity; detailed surveys underway
15 October	Moderate or severe bleaching					Summary of full extent and severity of bleaching; implications for the reef
Monthly						Updates on temperature trends and coral condition; also publish to web and email to all staff

EXAMPLE: **GREAT BARRIER REEF MARINE PARK AUTHORITY COMMUNICATIONS STRATEGY**

		Briefings			
Approx. date	Trigger[1]	Senior Management	Minister	Stakeholders	Message
1 Dec		^	^	^	Summer approaching; bleaching risk period; GBRMPA prepared
20 Dec		^			Temperature trends for December; plans for Christmas break
	High bleaching risk	^	^		Temperatures unusually high; coral bleaching event probable
	Moderate bleaching	^	^	^	High temperatures recorded; moderate bleaching observed; areas worst affected
	Severe bleaching[2]	^	^	^	Very high temperatures recorded; severe bleaching observed; areas worst affected; mortality likely
15 Feb[3]		^			Temperature trends for first half of summer; summary of reports of coral bleaching
31 March	No bleaching	^	^	^	Summer concluding; bleaching risk period over; no significant bleaching observed
	Moderate or severe bleaching	^	^	^	High water temperatures recorded during summer; bleaching observed; preliminary assessment of extent and severity; detailed surveys underway
31 April	Moderate or severe bleaching	^	^	^	Summary of full extent and severity of bleaching; implications for Great Barrier Reef
Monthly[4]		^			Updates on temperature trends and coral condition; also publish to web and email to all staff