Resilience Assessment of Coral Reefs

Rapid assessment protocol for coral reefs, focusing on coral bleaching and thermal stress

David Obura and Gabriel Grimsditch

IUCN Resilience Science Group Working Paper Series – No 4

IUCN Global Marine Programme

Founded in 1958, IUCN (the International Union for the Conservation of Nature) brings together states, government agencies and a diverse range of non-governmental organizations in a unique world partnership: over 100 members in all, spread across some 140 countries. As a Union, IUCN seeks to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable.

The IUCN Global Marine Programme provides vital linkages for the Union and its members to all the IUCN activities that deal with marine issues, including projects and initiatives of the Regional offices and the six IUCN Commissions. The IUCN Global Marine Programme works on issues such as integrate coastal and marine management, fisheries, marine protected areas, large marine ecosystems, coral reefs, marine invasives and protection of high and deep seas.

The Nature Conservancy

The mission of The Nature Conservancy is to preserve the plants, animals and natural communities that represent the diversity of life on Earth by protecting the lands and waters they need to survive. The Conservancy launched the Global Marine Initiative in 2002 to protect and restore the most resilient examples of ocean and coastal ecosystems in ways that benefit marine life, local communities and economies. The Conservancy operates over 100 marine conservation projects in more than 21 countries and 22 US states; they work with partners across seascapes and landscapes through transformative strategies and integrated planning and action. The focus is on: (1) Setting priorities for marine conservation using ecoregional assessments and tools for ecosystem based management; (2) Ensuring coral reef survival by creating resilient networks of marine protected areas; (3) Restoring and conserving coastal habitats by utilizing innovative new methods; (4) Building support for marine conservation through strategic partnerships and working to shape global and national policies. Marine conservation in The Nature Conservancy builds upon the organization's core strengths: achieving demonstrable results; working with a wide range of partners, including non-traditional partners; science-based, robust conservation planning methodologies; our experience with transactions; and, perhaps most importantly, our ability and commitment to back up our strategies with human, financial and political capital. For more information e-mail marine@tnc.org or go to www.nature.org/marine.

Acknowledgements
We would like to acknowledge the following programmes that contributed to the development of the protocol through their general work and supporting workshops and fieldwork: the International Union for the Conservation of Nature (IUCN), The Nature Conservancy, the Great Barrier Reef Marine Park Authority, the Coral Reef Targeted Research Programme for Management, World Wildlife Fund – US and Tanzania Programme Office, Living Oceans Foundation, Island Conservation Society, D'Arros Research Station, Seychelles Island Foundation, CORDIO and the Ministry of Foreign Affairs of Finland.

Editors
David Obura & Gabriel Grimsditch

Contributors
Paul Marshall, Naneng Setiasih, Greta Aeby, Lizzie McLeod, Alison Green, David Bellwood, Howard Choat, Haji Machano, Ameer Abdulla, Robert Steneck, Jerker Tamelander.

Cover Photography

Front cover: Bleached *Acropora* coral on the Great Barrier Reef, Queensland, Australia. Copyright: Paul Marshall, Great Barrier Reef Marine Park Authority, GBRMPA.

Back cover: Coral reef and research diver, Misali Island, Pemba, Zanzibar. Copyright: Jerker Tamelander, IUCN.

Resilience Assessment of Coral Reefs

Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress

Published by: IUCN, Gland, Switzerland

Citation: Obura, D.O. and Grimsdith, G. (2009). *Resilience Assessment of coral reefs – Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress*. IUCN working group on Climate Change and Coral Reefs. IUCN, Gland, Switzerland. 70 pages.

ISBN: 978-2-8317-1151-5

This is the official manual (2009 edition) of the Reef Resilience Assessment protocol developed by the IUCN working group Climate Change and Coral Reefs. For queries about the methods, please send them to the contacts below.

Available from:
IUCN Global Marine Programme, International Union for the Conservation of Nature,
Rue Mauverney 28, 1196 Gland, Switzerland.
Tel : +41 22 999 02 17 Fax: +41 22 999 00 25
E-mail: marine@iucn.org or Gabriel Grimsditch; ggrimsditch@iucnus.org

CORDIO East Africa (Coastal Oceans Research and Development – Indian Ocean)
9 Kibaki Flats, Kenyatta Beach
P.O.BOX 10135, Mombasa 80101, Kenya
Web: www.cordioea.org
David Obura; dobura@cordioea.org

This publication is available as a download from the IUCN Global Marine Programme website at the following address: http://www.iucn.org/cccr/publications/

A catalogue of IUCN publications is also available.

Printed in Switzerland on chlorine-free paper from FSC-certified forests.

Resilience Assessment of Coral Reefs

Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress

David Obura and Gabriel Grimsditch

IUCN Climate Change and Coral Reefs Marine Working Paper Series – No 4

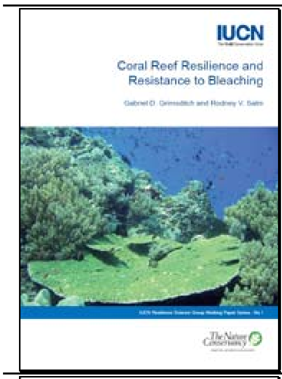
About the IUCN Climate Change and Coral Reefs Marine Working Group

The IUCN Climate Change and Coral Reefs Marine Working Group (formerly the IUCN Resilience Science Working Group), focused on coral bleaching, resilience and climate change, was established in 2006 by the Global Marine Programme of IUCN on a 3-year grant from the John D. and Catherine T. MacArthur Foundation. The goal of the working group is to draw on leading practitioners in coral reef science and management to streamline the identification and testing of management interventions to mitigate the impacts of climate change on coral reefs. The working group consults and engages with experts in three key areas: climate change and coal bleaching research to incorporate the latest knowledge; management to identify key needs and capabilities on the ground; and ecological resilience to promote and develop the framework provided by resilience theory as a bridge between bleaching research and management implementation.

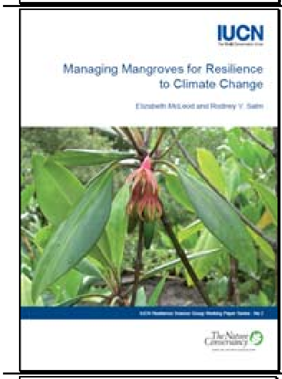
One of the outputs of this group was the setting up of a website that provides links to projects, events, partners and publications.

For more information, see http://www.iucn.org/cccr/publications/

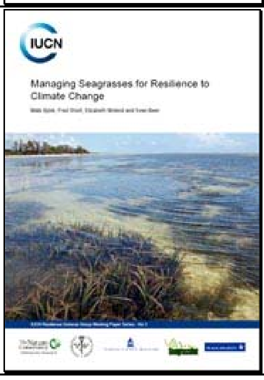
This publication is the 4th in a series of publication on management tools to promote resilience in marine ecosystems. The other three, also available from IUCN's Global Marine Programme are listed below:



Coral Reef Resilience and Resistance to Bleaching
Gabirel D. Grimsditch and Rodney V. Salm
© IUCN/TNC, October 2006



Managing Mangroves for Resilience to Climate Change
Elizabeth Mcleod and Rodney V. Salm
© IUCN/TNC, October 2006



Managing Seagrasses for Resilience to Climate Change
Mats Björk, Fred Short, Elizabeth Mcleod and Sven Beer
© IUCN/TNC, September 2008

Table of Contents

1. Introduction 8
  1.1. Coral reefs, climate change, and reef resilience 8
  1.2. Resilience definitions 9
  1.3. Justification 9
  1.4. Using resilience in management 9
  1.5. Goal and objectives 10
  1.6. Scope of resilience assessment 10
    1.6.1. Coral reef compartments 10
    1.6.2. Drivers of resilience 11
  1.7. The resilience assessment protocol 13
2. Survey design 15
  2.1. Site selection 15
  2.2. Sampling time 15
  2.3. Safety 16
  2.4. Overview of methods 16
    2.4.1. Visual estimation of indicators 16
    2.4.2. Quantitative methods 17
  2.5. Team composition and skills 17
  2.6. Equipment 18
  2.7. Desk study/background information 18
    2.7.1. Environmental 18
    2.7.2. Reef status and history 19
    2.7.3. Anthropogenic threats 19
3. Field methods 20
  3.1. Benthic cover 20
    3.1.1. Objective 20
    3.1.2. Indicators 20
    3.1.3. Methodology 20
      3.1.3.1. Photoquadrats 20
      3.1.3.2. Algal community 22
    3.1.4. Materials 22
    3.1.5. Observer skills 22
    3.1.6. Background data 22
  3.2. Coral community composition 23
    3.2.1. Objective 23
    3.2.2. Indicators 23
    3.2.3. Methodology 23
    3.2.4. Materials 24
    3.2.5. Observer skills 24
    3.2.6. Background data 24
  3.3. Coral size classes and population structure 25
    3.3.1. Objective 25
    3.3.2. Indicators 25
    3.3.3. Methodology 25
      3.3.3.1. Size class and recruitment 25
      3.3.3.2. Maximum size of corals 27
    3.3.4. Materials 27
    3.3.5. Observer skills 27
    3.3.6. Background data 27
  3.4. Coral condition and threats 28
    3.4.1. Objective 28
    3.4.2. Indicators 28
    3.4.3. Methodology 28
    3.4.4. Bleaching and mortality 29
    3.4.5. Coral diseases and other conditions 30
    3.4.6. Other threats 30
    3.4.7. Materials 31
    3.4.8. Observer skills 31
    3.4.9. Background data 31

3.5. Fish community structure and herbivory 31
3.5.1. Objective 31
3.5.2. Indicators 31
3.5.3. Methodology 31
3.5.3.1. Functional groups 31
3.5.3.2. Herbivore functional groups 33
3.5.4. Sampling 35
3.5.4.1. Long swim 35
3.5.4.2. Transects/point counts 36
3.5.5. Materials 36
3.5.6. Observer skills 36
3.5.7. Background data 37
3.6. Site resilience factors 37
3.6.1. Objective 37
3.6.2. Indicators 37
3.6.3. Methodology 37
3.6.4. Data sources 37
3.6.5. Approach 37
3.6.5.1. 5-point scale 38
3.6.5.2. Spot vs. continuous measurements 38
3.6.6. Resilience indicators 38
3.6.6.1. Benthic indicators 38
3.6.6.2. Substrate and reef morphology 39
3.6.6.3. Cooling and flushing 40
3.6.6.4. Shading and screening 40
3.6.6.5. Extreme conditions and acclimatization 41
3.6.6.6. Coral condition 42
3.6.6.7. Coral population structure 43
3.6.6.8. Coral associates 44
3.6.6.9. Fish functional groups - herbivory 45
3.6.6.10. Connectivity 45
3.6.6.11. Anthropogenic factors - negative 46
3.6.6.12. Anthropogenic factors – positive (management) 47
3.6.7. Materials 48
3.6.8. Background data 48
4. Data management and analysis 49
4.1. Archiving and storing data 49
4.2. Data analysis 49
4.3. Reporting and publication 49
5. References 51
6. Resources 52
6.1. Benthic cover .... **Error! Bookmark not defined.**
6.2. Coral community structure (genera) .... **Error! Bookmark not defined.**
6.3. Coral size class distributions (selected genera) .... **Error! Bookmark not defined.**
6.4. Coral condition .... **Error! Bookmark not defined.**
6.5. Fish community structure - herbivores .... **Error! Bookmark not defined.**
6.6. Resistance and resilience indicators .... **Error! Bookmark not defined.**
6.7. Data entry and analysis .... **Error! Bookmark not defined.**
7. Field Datasheets 53
7.1. Coral genera 53
7.2. Coral sizes 54
7.3. Condition 55
7.4. Fish-herbivore functional groups 56
7.5. Fish-basic functional groups 57
7.6. Resistance/resilience factors 58
8. Resilience Indicators Table 59

Good recovery on a solid reed framework (left) compared to no recovery on unconsolidated branching framework (right) By Jerker Tamelander, IUCN

1. Introduction

1.1. Coral reefs, climate change, and reef resilience

Coral reefs and their associated seagrass beds and mangrove habitats support the highest marine biodiversity in the world. More than 500 million people worldwide depend on them for food, storm protection, jobs, and recreation. Their resources and services are worth an estimated 375 billion dollars each year, yet they cover less than one percent of the Earth's surface. Unfortunately, many of the world's coral reefs have been degraded, mainly due to human activities. According to the Status of Coral Reefs of the World: 2004, 70% of the worlds' coral reefs are threatened or destroyed, 20% of those are damaged beyond repair, and within the Caribbean alone, many coral reefs have lost 80% of coral species.

Climate change is now recognized as one of the greatest threats to coral reefs worldwide. While a changing climate brings many challenges to coral reefs, one of the most serious and immediate threats is from mass coral bleaching associated with unusually high sea temperatures. Coral bleaching has lead to substantial damage to coral reefs on a global scale (16% of reefs suffered lasting damage in 1998 alone), with some areas losing 50-90% of their coral cover (Wilkinson 2000). Further degradation is predicted: severe coral bleaching events may be an annual occurrence by mid-century, even under optimistic climate scenarios (Hoegh-Guldberg 1999, Hughes et al. 2003).

The amount of damage depends on not only the rate and extent of climate change, but also on the ability of coral reefs to cope with change. Importantly, the natural resilience of reefs, that maintains them in a coral dominated state, is being undermined by stresses associated with human activities on the water and on the land. Unmanaged, these stresses have the potential to act in synergy with climate change to functionally destroy many coral reefs and shift them to less diverse and productive states dominated by algae or suspension feeding invertebrates. Coral reefs are under pressure from a variety of human activities, including catchment uses that result in degraded water quality, unsustainable and destructive fishing, and coastal development. These local pressures act to reduce the resilience of the system, undermining its ability to cope with climate change, and lowering the threshold for the shift from coral-dominated phase to other phases. Increasingly, policy-makers, conservationists, scientists and the broader community are calling for management actions to restore and maintain the resilience of coral reefs to climate change, and thus avoid worst-case scenarios.

Two general properties determine the ability of coral communities to persist in the face of rising temperatures: their sensitivity and their recovery potential. Sensitivity relates to the ability of individual corals to experience exposure without bleaching, and if they bleach to survive. Recovery potential relates to the community's capacity to maintain or recover its structure and function in spite of coral mortality. These properties at the coral colony and coral community level are termed 'resistance' and 'resilience', respectively (West and Salm 2003, Obura 2005, Grimsditch and Salm 2006). Together, they determine the resilience of coral communities to rising sea temperatures.

1.2. Resilience definitions

Resistance – when exposed to high temperature and other mitigating factors, the ability of individual corals to resist bleaching, and if bleached to survive.

Resilience – following mortality of corals, the ability of the reef community to maintain or restore structure and function and remain in an equivalent 'phase' as before the coral mortality.

1.3. Justification

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. Earlier attempts have been limited to post-event questionnaire assessments (Salm and Coles 2001, www.reefbase.org) with limited application and problems of subjectivity and applying the findings to management (Obura and Mangubhai 2003). 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.

This document outlines a protocol that is one attempt at defining some basic resilience indicators that can be quantified using rapid assessment methods. These will serve two primary purposes:

1) ***To provide simple methods that are applicable in a wide variety of developing country settings.*** *A large of percentage of the world's coral reefs is located in developing countries with low resources and capacity available for management and monitoring. Although monitoring of resistance and resilience indicators can greatly improve coral reef management in the face of climate change, these parameters are related to oceanographic phenomena and ecological community characteristics that are relatively expensive and time-consuming to study in detail. Therefore it is of great importance to develop rapid assessment methods for low-resource scenarios that can be used effectively in coral reefs areas around the world.*

2) ***To provide a first assessment of outcomes in coral reef conservation****. Although Marine Protected Areas (MPAs) cannot prevent the stresses that cause coral bleaching (increased temperature and radiation), it is possible that they could improve resistance and resilience of coral reefs by protecting them from other stresses (for example fishing pressure) and thus minimizing coral mortality and/or allowing the community to recover from bleaching events. However, to date the success of MPA management practices in influencing bleaching resistance and resilience has not been systematically quantified on larger scales. To aid an assessment of the effectiveness of coral reef conservation measures in the face of climate change it is necessary to develop easily-applicable resilience indicators that can be monitored in MPAs around the world.*

1.4. Using resilience in management

The ability of managers to adapt to climate change will be critical to the future of coral reefs, and also for the social and economic services that they provide. While science is providing important insights about the impacts of climate change on coral reef systems, strategies for managing them in a changing climate are only just emerging (Marshall and Schuttenberg 2006). There is now an urgent need to test and refine these ideas, and to accelerate learning through sharing management experiences – successes and failures – in responding to the challenges of climate change.

One of the major challenges for progressing resilience-based management lies in successful application. While general resilience principles are influencing the way practitioners approach coral reef management and conservation, there remains an urgent need for an operational tool for assessing and mapping resilience in coral reef ecosystems. Drawing on current and emerging resilience thinking, this document explores coral reef resilience in operational terms, and outlines a suite of variables that are likely to be useful indicators of reef resilience in a management context, and a protocol for measuring them.

1.5. Goal and objectives

The protocol 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.

1.6. Scope of resilience assessment

Ecological resilience relates to the entire scope of positive and negative factors affecting a community, such as resource extraction, pollution and invasive species. This assessment method focuses on climate impacts, in order to focus manager's efforts to limiting them, however these cannot be assessed in isolation, and information on the other threats facing a reef is necessary to distinguish the role of climate threats. To operationalize resilience for assessment, the scope of the concept, in defining which components of the reef community to measure, and in identifying which processes are the main drivers of community structure and health is necessary.

1.6.1. Coral reef compartments

There is a huge complexity of factors, species and compartments that make up a coral reef. The primary ones for the assessment to focus on need to be identified, alongside considerations of ease of measurement using visual reef assessment practices. We identify four levels at which to structure the reef: (see Fig. 1 below)

1) the primary biotic compartments that make up the reef community and have been the focus of visual assessment of reefs for three decades: corals, algae and fish/consumer communities;
2) the ecological interactions that drive dynamics within and among these groups, including from members of the coral reef community that are not within the groups in (1) above;
3) habitat and environmental influences that directly affect these compartments and the interactions between them; and
4) external drivers of change, including anthropogenic and climate factors.

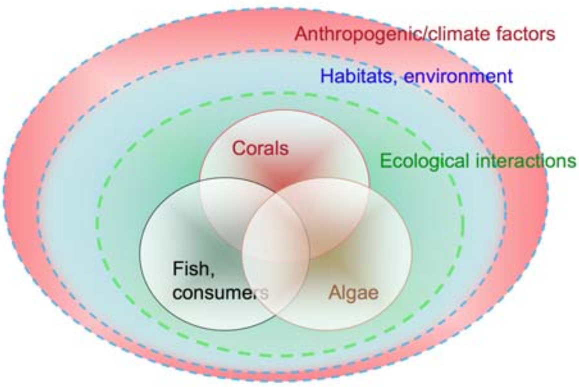


Fig. 1. Resilience compartments model, coral reefs.

In considering the above, it is important to note that both pattern (state) and process (function) indicators and variables may be useful for measurement and interpretation. Both may be affected by drivers of resilience.

1.6.2. Drivers of resilience

Balance in the coral reef community is affected by a vast array of processes, but these can be differentiated into strong and weak drivers of change. In developing the resilience model that is the basis for assessment, the strong drivers of resilience, or of shifts away from a resilient coral community need to be identified. These drivers may act from one reef compartment to another (e.g. fish to algae), or across different levels (e.g. anthropogenic factors to corals). The importance of incorporating the latest science in identifying the strongest and most active drivers, and which may change under different conditions and in different locations, is paramount.

A summary of the strong drivers, are the following:

Connectivity. Currents disperse coral larvae enabling re-seeding of impacted reefs from refuge populations of hard corals. Connectivity provides many other functions as well, such as in the provision of ecosystem services, such as ecological interactions between adjacent reefs (vagile predators/herbivores). In the broader sense, connectivity includes factors such as available substrate and successful settlement of larvae.

Physical/chemical factors. The physical/chemical environment is a key determinant of resilience by determining the environmental envelope within which a reef community exists. In considering these, however, it is important to understand the local environment, as reefs have thrived in very different conditions (e.g. natural oligotraphic vs eutrophic areas). Of key concern here are proximity to thresholds, and/or levels of variability that might convey vulnerability to changes considered under anthropogenic effects. The complexity of interactions and compartments that relate to water quality, nutrients and microbial activity (fig. 2) precludes simple explanations. Additionally, physical processes affecting circulation around bays, headlands, etc may fundamentally affect other physical and ecological processes, and these differences must be considered when establishing underlying conditions.

Algal-coral dynamics, and therefore algal control through herbivory are both strong drivers of reef state, as well as indicators of phase shifts from corals to algal dominance, or vice versa. Algal populations have a strong influence on the recovery of coral communities following coral mortality, and algal competition or microbial enhancement by algae may also affect the susceptibility of corals to bleaching (Smith et al. 2006). A number of different herbivore functional groups are recognized that mediate coral-algal dynamics in different ways, and the diversity of species and of their vulnerability to stresses strongly affects how robustly each functional group contributes to reef resilience. Fish are the primary taxonomic group controlling herbivory, though under degraded conditions, sea urchins become important.

Anthropogenic factors may change any of the enclosed compartments in the figure, and drivers listed above. For example, environmental factors may be altered by anthropogenic stresses such as coastal development, and this may alter key drivers of resilience, such as circulation that affects thermal stress. Similarly, fishing may affect the balance and actions of herbivore functional groups. Adding complexity to the role of nutrients and physical/chemical processes, anthropogenic alterations of water and substrate quality may have very complex impacts on reef processes.

Thermal stress. The assessment method is focused on climate change impacts, in particular coral bleaching due to thermal stress. Thus greater focus in the methodology is given to this, and to factors that affect it. Climate change-induced thermal stress is driven by large pools of warm surface waters, driven by climate and oceanographic factors. The manifestation of these warm pools at the local level is affected by regional to local environmental factors such as cooling and flushing that reduce the temperature experienced locally. Synergistic stress by light is affected by shading and screening factors that reduce the degree of stress. Biological factors are also important, such as the intrinsic stress resistance of corals or zooxanthellae, and acclimatization driven by local patterns of variability and warming/cooling trends over the coral lifetimes.

The primary focus of this assessment protocol is on the effect of climate change on thermal stress on corals, for which the strong drivers summarized above are added into the general model from Fig. 1 (see Fig. 2). Many other processes may affect this model and can be incorporated as needed for a particular instance, the resilience framework providing a context to help identify the strong drivers that maintain reef health and minimize vulnerability.

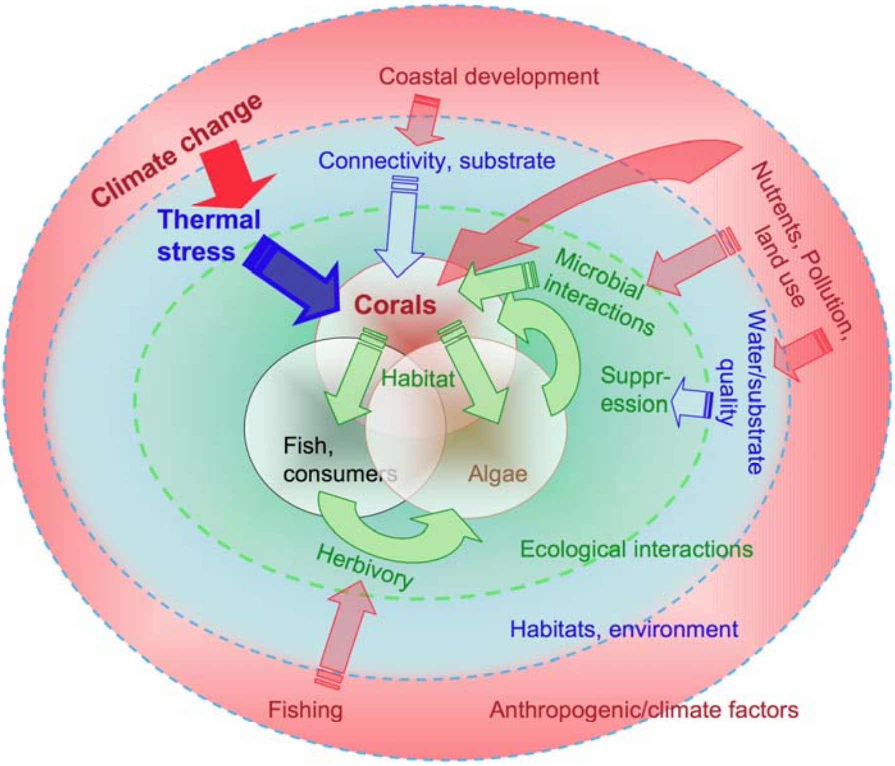


Fig. 2. Stron drivers for climate change impacts on coral reefs.

Many other drivers affect coral reefs, and these need to be considered for the local context when customizing the method to a new area. For example, crown of thorns seastar outbreaks may play a locally ‘strong‘ role, and the purpose of initial literature surveys and consultations is to ensure these are catered for. There is also a difference between ‘slow‘ and ‘fast‘ drivers of resilience. Slow drivers may cause small or near-zero increments of change over a long time but push the system to a threshold beyond which change happens quickly and potentially irreversibly (e.g. pollution). Fast drivers tend to cause large increments over a short time (e.g. mass bleaching event). These may play different roles at different times, and particularly may affect phase shift reversals. Finally, drivers important in phase shift reversals are poorly known, such as of rehabilitating algal communities to coral reefs. These may be mediated by actors or processes relatively dormant or inactive under normal conditions. The importance of an open approach to monitoring and assessment is therefore essential.

Thus the model and methodology are first an application of general resilience principles in assessment of the state of a reef community and the strong drivers affecting it, with a primary focus on thermal stress as the climate change threat and key driver affecting reefs today. The methodology could be adjusted to deal with other important threats as needed at individual sites.

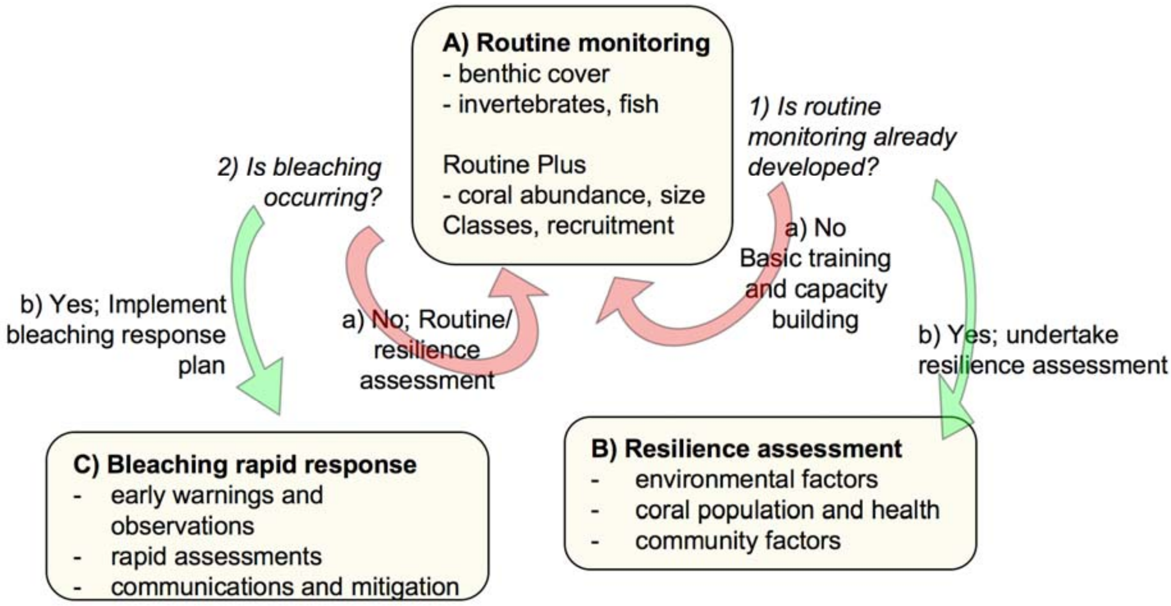


Fig. 3. Nested approach to monitoring resilience, building additional resilience indicators onto routine monitoring approaches (step 1b). During a bleaching event (step 2b) a subset of resilience indicators would be included in bleaching assessment protocols (Oliver et al. 2004).

1.7. The resilience assessment protocol

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 (see Figure 3 above). Thus routine monitoring (A in Fig 3) 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 in Fig 3). 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 in Fig 3).

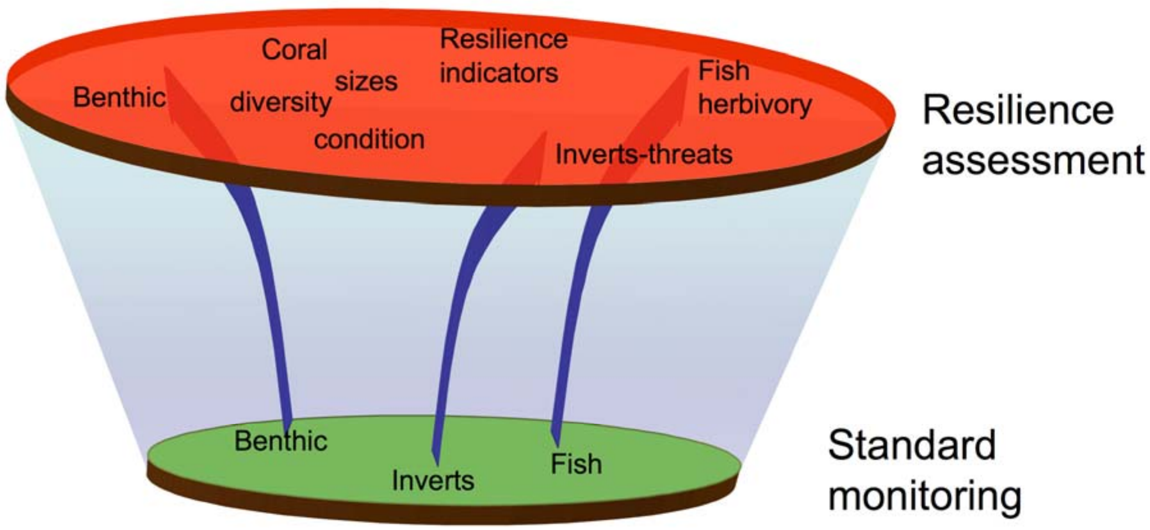


Fig. 4. The resilience assessment builds on a foundation from standard monitoring procedures, and other studies, adding further detail on coral community and site-based resistance/resilience to bleaching.

The main innovations of this resilience assessment are:

- More detailed measurements of coral populations (size classes, recruitment, etc), focused on selected genera with different susceptibilities to bleaching, and linked with measurements of coral health and condition
- More detailed measurements of algal height as a proxy for biomass
- Fish sampling focused on herbivorous fish, to estimate more precisely the potential controlling effect of herbivory on the benthic community
- Estimation of potentially important resilience factors, as quantitative measurements of such a wide variety of variables is not feasible in most reef monitoring situations
- Identification of indicators that affect thermal stress at a local site to assist in managing reefs within different vulnerabilities to warm surface pools

For the most reliable interpretation of the above information, good knowledge of the current status and recent history of the study reefs is necessary. Thus a literature review of local studies and monitoring programmes, and consultation with scientists and managers familiar with the local setting, are necessary.

This document is a product of the IUCN Working Group on Climate Change and Coral Reefs. It has been produced to support a globally coordinated program that will test and further refine an approach for assessing coral reef resilience as the basis for resilience-based management. The experience from this program will underpin the development of a formal framework for assessing resilience in coral reef ecosystems.

2. Survey design

The focus of the rapid assessment is on resistance and resilience of corals and the reef community to climate change (thermal stress). The methodology takes the resilience principles and compartmentalization of the coral reef community and strong drivers outlined earlier, and organizes them into a practical set of field measurements.

2.1. Site selection

Site selection is essential in order to cover a broad range of sites in terms of health, reef habitat and zone and potential influence of the factors that may affect coral bleaching and recovery.

The goal is to survey two depth contours, recognizing that strongest impacts of bleaching are in very shallow water (< 8 m), with in many places a critical depth of 10-15 m below which levels of bleaching and mortality are much less. Operationally, sites should be selected at approximately 3-5 m (or shallower) and 10-12 m below the lowest low tide, the deepest samples also being bound by dive-time restrictions and the need for sufficient sampling time to record all parts of the dataset. However, on many reefs, the highest coral cover will not be found at these exact depths, and adjustments should be documented and justified in the local site methodology.

The basic selection to criteria to consider should be:

1) ***Depth*** – include shallow (< 5 m) and deeper (operationally, 10-15 m, as deeper than that time restrictions severely curtail sampling ability. With many divers, it might be feasible to do > 15 m). This covers factors related to temperature and stratification, as well as to recovery speeds of corals and growth rates of algae.

2) ***Habitat*** – include a mix of windward, leeward, channel and lagoon sites, or other relevant features according to the area being studied.

3) ***Connectivity and currents*** – a transect along and across major currents and axes of water movement.

4) ***Land - ocean influence*** – a transect from land-based influences to oceanic influences may affect aspects of turbidity, water quality and access by resource users.

5) ***Management regime*** – to include differential effects of management on reef ecology.

6) ***Distance from human settlements*** – as a proxy for some human impact variables.

Site selection is assisted by having detailed coastal and bathymetric charts and recent high-resolution remote sensing images, such as LandSat/SPOT, and preferably QuickBird and other similar technologies, or aerial photographs. A hand-held or dive-boat based GPS and depth sounder help finding appropriate sites in the field, and for recording location. All sites must be marked by GPS (in degree units, not UTM), and backed by a site description and shore-based lines of sight if possible. Where additional detail is possible and for local needs, beginning and end-points of sampling can also be recorded by GPS.

A multivariate analysis is used to identify the factors that most strongly explain patterns in the dataset. Accordingly the larger the number of sites, the better discrimination there will be. Thus aim at sampling as many sites as possible, that is, completing all measurements of a single 'site' in one dive of the sampling team. For example, deep and shallow sites sampled adjacent to each other can be done as 1st and 2nd dives of the survey team.

2.2. Sampling time

This will vary with different teams, however as a rule of thumb, 60-minutes of data collection has been found to be necessary for a single site (ie. for the fish observer to record the swim and 3 transects, and each coral size observer to record two transects). In practise, this may mean planning for dives of approx. 70 minutes. With dive depths restricted to < 12 m, this is feasible and well within safe-diving limits. With moderate boat/dive support two dives are possible each day. With excellent boat/dive support it will be possible to sample three sites per day.

2.3. Safety

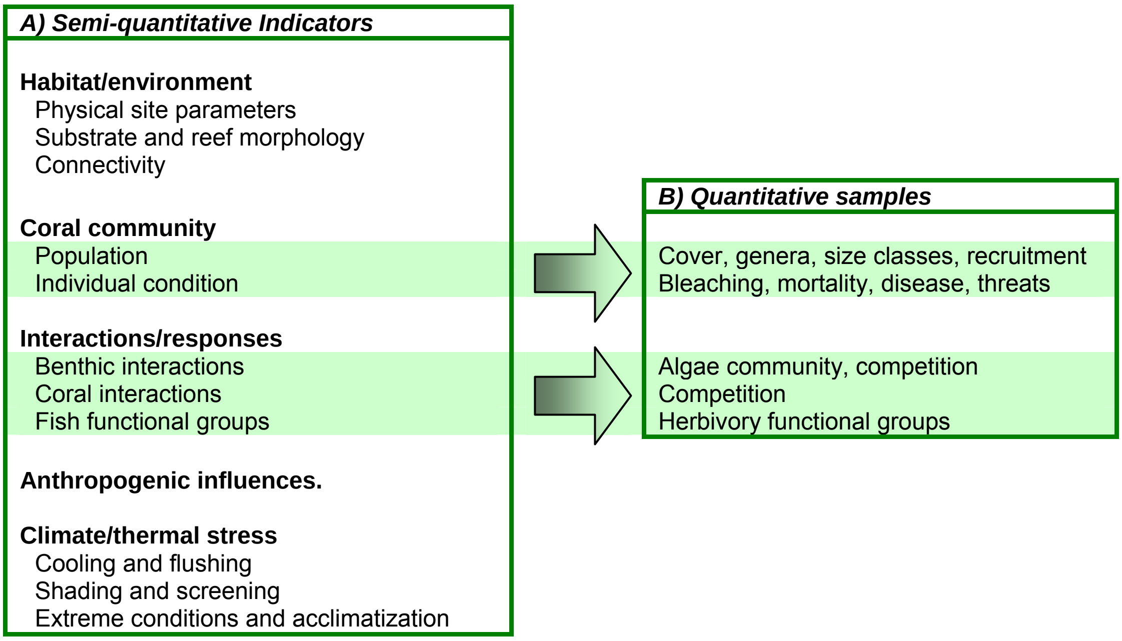
Safety of divers is the number one priority. No surveys should be undertaken when weather or sea conditions are unsafe or if a diver does not feel well. In particular, teams should plan work to avoid decompression dives during survey. Any diver who is not comfortable diving for any reason should NOT participate in the diving aspects of the survey.

2.4. Overview of methods

The resilience assessment is designed to:

1) Provide an overarching semi-quantitative assessment of all components of reef resilience with respect to climate change, through estimation of indicators grouped under key compartments/drivers of reef resilience, and

2) For the key compartments and strongest drivers with respect to thermal stress and bleaching, quantitative measures that enable more in-depth assessment of status and health.



<u>2.4.1. Visual estimation of indicators</u>

A semi-quantitative scale (Likart) of 1-5 is used for estimation of all the resilience indicators, including those for which more detailed quantitative data will be collected. The 5-point scale was selected to facilitate estimation of minimum (1), maximum (5) and moderate (3) level for each indicator for the region of application, and intermediate levels of low (2) and high (4). In general the direction of the indicator is selected such that 1 designates low/poor/negative conditions for corals and 5 high/good/positive conditions. Indicators are grouped into clusters, as per the table above.

Because the indicators are semi-quantitative, there is considerable scope for subjective bias, and a high level of experience is required in their estimation. Thus this component needs to be done by an experienced scientist with considerable experience at the study location and in the region surrounding it.

2.4.2. Quantitative methods

The focus of the quantitative methods is to build on past and current coral reef monitoring programmes. This adds value to the information already collected by monitoring programmes, and maximizes the interpretability of the new data on the basis of historic data. This approach also enables capacity building of existing monitors/observers, so that staff, students and scientists that have been the backbone of past monitoring activities can also be the primary implementers of this methodology. For standardization of sampling among the components of the methodology, across locations and teams that will apply it, and having considered the broad range of monitoring protocols currently being applied, belt transects have been selected as the units of sampling – of 25*1 m for most benthic variables, and 50*5 m for fish, and some variables are scored at the whole-site level. A summary of the quantitative methods is given below:

Quantitative component	***Method/approach***
Benthic cover	Compatible with main long term monitoring approach in the area. Preferred – photo-quadrats analyzed using computer software. Alternatives – Line Intercept transects, quadrats and other *in situ* methods.
Coral community structure (genera)	Visual estimate of relative abundance of genera at the study site, in 5 classes – dominant, abundant, common, uncommon, rare.
Coral size class distributions (selected genera)	Belt transects (25 * 1 m) with subsampling using quadrats for small colonies < 10 cm. 15-20 selected genera, in doubling size classes (0-2.5, 2.6-5, 6-10, 11-20 cm. etc)
Coral condition and threats	Incidence of coral condition and threats - bleaching, disease, predation, other conditions and mortality. Sampled in the 25*1 m belt transects then in the general study site.
Fish community structure – focus on herbivores	Long swim (400* 20 m) or general site observation of large indicator fish, and belt transects (50 * 5 m) recording the main functional groups at the lowest taxonomic level possible, and focusing on herbivore functional groups.

2.5. Team composition and skills

The skills required for each component of the methodology are detailed in each relevant section, and there is overlap in skills that might be good for different parts. In general, a team of 4 or 5 would be ideal, though the work can be done with 2 or 3 with compromises. In the tables below, 'X' represents a primary responsibility, and '-' represents an optional responsibility dependent on expertise. These are given as guidance only, as the skills available in different team members may allow more optimal allocation of duties. If this is done, then the field datasheets can be adjusted to best suit the team members available.

Skill levels of 'high', 'mid' and 'low' are indicated. These are just indicative. In general there must be one person very familiar with and who can lead the benthic work and score the resilience indicators, and one very familiar with fish. Skills for the others on the team can be built up through on-site training, and it may be necessary to assign 1-3 days for training to achieve a consistent level of data collection.

	Expertise	***Level***	***1) Resilience indicators***	***2) Benthic cover***	***3) Coral genera***	***4) Coral sizes***	***5) Coral cond***	***6) Fish***
1	Community/coral	High	X		X			
2	Coral	Mid				X	X	
3	Coral	Low		X		X		
4	Fish	High						X
5	Fish	Low						X

2.6. Equipment

The full list of equipment required for the surveys is summarized below. Details are given within each section.

	Underwater	*Specialized, dry*
General	Temperature loggers (see below)	GPS, depth sounder Charts, high-resolution remote sensing images
1) benthic cover	Digital camera with UW housing	Computer Software (Coral Point Count, or Adobe Photoshop or equivalent)
2) coral diversity	Datasheet	
3) coral size class	Transect line, 25 m (one per observer or pair of observers) 1m ruler/stick marked at 10, 20, 40 and 80 cm to help guide size estimates (3/4" PVC tube ideal for this). One per observer. Slate, marked along its top with 5, 10 and 20 cm to help guide size estimates Datasheet	Genus guide for corals
4) coral condition	- use line from coral size class Datasheet, with checklist of disease/condition codes	Detailed ID resource of coral diseases and lesions.
5) fish herbivore populations	Transect line, 50 m (may be useful to have two, one for each buddy in a team) Datasheet, with ID sheet of main groups	Detailed ID resource.
6) resilience indicators	Datasheet	Indicator/criterion table for constant updates.

2.7. Desk study/background information

To interpret resilience variables and indicators, knowledge of their context is necessary, and this may incorporate past, present and future aspects. These include environmental and human dimensions, and a variety of sources will be needed.

2.7.1. Environmental

In the context of this study, temperature (thermal stress) is the key independent variable against which resilience (of corals to bleaching) is being evaluated, and there are a number of other variables that influence and co-vary with temperature and also influence resilience. Thus seawater temperature is the primary indicator to quantify, followed by a number of oceanographic patterns that influence its variability such as currents, upwelling, and periodic cycles. Because of the linkages between ocean and atmosphere, atmospheric variables can provide useful proxies for variation in sea temperatures. Air temperature and a number of other variables such as winds, rainfall and solar radiation can be related to sea surface temperature patterns. And because they in many cases have longer historical records and are used more commonly than ocean variables in long term projections, can serve as proxies for variability and trends in seawater temperatures. Additionally, because radiation interacts strongly with temperature in causing stress in corals, variables that affect solar radiation and heating at the sea surface are also useful.

Background data for assessing reef resilience:

Area	Purpose	Datasets
Local climate – seawater temperature	Variability and trends in sea surface temperature	*In situ* datasets on seawater temperature, light penetration, etc.
Local climate - meteorological and oceanographic	Proxies for medium term patterns in local climate - seasonal/annual variability	Air temperature, rainfall, wind speed/direction, radiation, sunhours/cloud cover, storms/cyclones, waves, long term seawater temperatures
Regional climate – long term trends	Long term trend indicators and projections	Available regional climate/sea change scenarios

The greater the scope of background data that can be collated is better. While primary data at the local site are most desirable, in many cases datasets may only be available from nearby locations (e.g. a city/airport) or at larger scales (e.g. climate variability/trends).

2.7.2. Reef status and history

Particularly if the area has already been the focus of conservation and protection actions, historical data on reef status should be available, and ongoing monitoring may be underway. Historical research on different aspects of reef ecology, and particularly any aspects related to variables recorded in the assessment protocol should be compiled. If a long term monitoring programme is underway in the area, or in nearby areas such that data sharing in a network is possible, then the protocol should be customized to match the existing methods and/or the existing methods should be updated to be consistent with the protocol – this allows more in-depth analysis of data recorded here against past data.

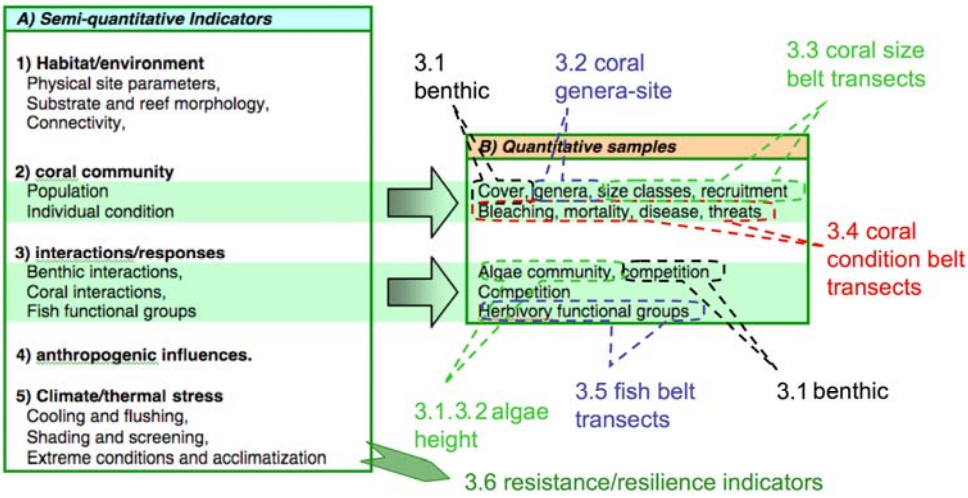
2.7.3. Anthropogenic threats

Documentation of anthropogenic threats from the literature or in many cases government/official statistics can be crucial in ensuring accuracy of the survey results. Thus demographic data can help scale survey data on fisheries and pollution effects. Any past studies quantifying anthropogenic impacts to the area, such as fishery catch data, or pollution monitoring, should be compiled.

3. Field methods

The description of the field methods focuses on efficient application in the field, so does not linearly follow the structure of sampling set out in “2.4 Overview of methods”.

The figure below indicates each of the detailed quantitative methods (B) – the part of the overall dataset they provide and their order of presentation in the next sections. The semi-quantitative resilience indicators (A) are described in detail in section 3.6.



3.1. *Benthic cover*

3.1.1. Objective

Benthic cover focusing on broad benthic categories and the algal community, important in assessing phase shifts of coral reef communities to other forms.

3.1.2. Indicators

- Percent of overall benthic cover for benthic cover classes
- Percent of benthic cover by coral genus.
- Benthic algae abundance and composition

3.1.3. Methodology

3.1.3.1. Photoquadrats

Digital still photographs of the reef substrate are taken from a height of approximately 0.6-0.75 meters above the substrate. Natural light is used in waters < 5 m deep with fill-in flash at deeper depths or on overcast days. A red-shift can also be set within the camera, to enhance reds and help distinguish classes such as coralline algae. Photographs can be taken haphazardly over a study site, counting 3-4 between frames and ensuring successive images do not overlap. As a guide, photographs can be taken of the coral size-class transects to ensure the photographs are representative of the other data being collected. Alternatively, to minimize over-sampling of just one part of the study site, groups of 5 photos can be taken together with spaces of > 10 m between each group. Over 40 (about 45) photographs should be collected, see below.

Photographs are downloaded onto a computer, and analysed for benthic composition and coral cover using dedicated software such as Coral Point Count (Kohler and Gill 2006, see resources section 6). Alternatively, generic software such as Adobe Photoshop can be used, where it is possible have several layers in one image. 25 points are used for recording data from each photograph. In Adobe Photoshop, this can be done by creating a new layer containing 25 circles (letter “o” in yellow shows up best), evenly spaced over a sample photograph.

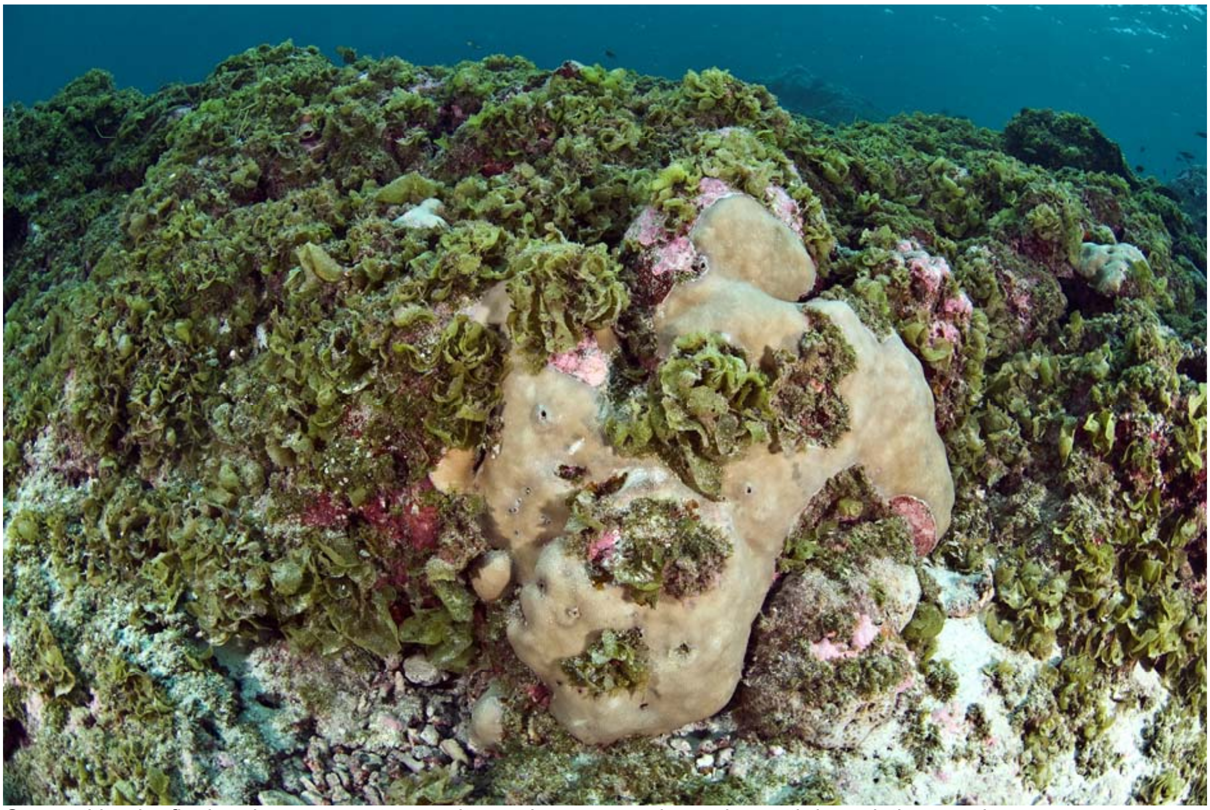
To obtain results with sufficient accuracy and replication, the results for 4 images are combined together to form one sample, or ‘transect’, of 100 points (this is easily done in CPCe). The images for one transect can be sequential, but alternatively, to reduce sampling bias, can be randomly selected from the available images using a random number generator. Not less than six of these transects (i.e. 24 images) are needed to calculate the mean and standard deviation of cover types, and preferably 10 ‘transects’ (40 images) should be scored for each site. To ensure sufficient images are available, > 45 photographs should be captured for each site, to also allow for out-of-focus/problem photos.

The benthic substrate beneath each circle is identified according to the ability of the observers, with Table 2.1 showing a hierarchy of levels useful for assessing resilience, adapted from English et al. (1996). In general, enter data in more detailed categories and subsequently analysis can be done at more aggregated levels depending on the need.

Priority among the categories is weighted towards cover types that are important both because they are indicators of the phase/state of the reef (hard and soft corals, other invertebrates and coralline, turf and fleshy algae), and when abundant tend to exert a strong controlling influence on competitors.

Benthic categories for identification:

Basic	***Intermediate***	***Detailed***
Hard coral	Growth form	Genus
Soft coral	Growth form	Genus
Other inverts	Corallimorpharia, sponge, other	Major taxa (e.g. *Tubipora*, gorgonian, corallimorph, zooanthid, hydroids, sponge, ascidian, other)
Fleshy algae	*Halimeda*, brown macroalgae, green macroalgae, calcareous algae	Genera
Turf/algal assemblage		Thickness classes
Coralline algae		Encrusting, nodular, rubble
Recent dead coral	-	-
Rubble	-	Size
Microbial	Mats, filaments	-
Sand	-	-
Seagrass	-	Genera



Competition by fleshy algae prevents recruitment by new corals, and growth by existing corals
By – Peter Verhoog

3.1.3.2. Algal community

Measurement of algal biomass is not possible in a rapid assessment approach, but it can be approximated by measurement of algal canopy height (see AGGRA, Robert Steneck pers. comm.). Fleshy algae is differentiated from turf algae by height (> 1 cm) and that the structures that differentiate genera can begin to be seen.

This measurement is done in the same 1m^2 quadrats as sampled for small corals see section 3.2.3) as follows:

- Estimate the % cover of all the macroalgal components within the 1m^2 quadrat;
- For each component for which cover is estimated, measure the average height of algal fronds. This may require several measurements of vertical height – write the individual heights onto the datasheet, and the average will be calculated during analysis.

Macroalgae components can be identified at different levels of resolution to suit the observer. Note that if genera/finer scale taxa are identified, also estimate the cover at the broad scale to ensure that the sum of genus % cover adds up to the same value as the broad categories.

Broadest groups	***Intermediate***	***Fine (e.g. major genera)***
Fleshy algae	red	…
	brown	*Sargassum, Dictyota, Stypopodium,*
	green	*Ulva, Dictyosphaeria,*
Calcareous algae		*Halimeda* and oher calcareous genera

3.1.4. Materials

Wet	***Dry***
Digital camera with UW housing	Computer
1m^2 quadrat – algae cover	Software (Coral Point Count CPCe; Adobe Photoshop or equivalent that can handle multiple layers in an image)
Ruler (cm) – algal canopy height	

3.1.5. Observer skills

In-water - A single observer, comfortable with diving and handling a camera underwater. May be familiar with benthic monitoring techniques. Must be able to make unbiased selection for photoquadrats, ensure high-quality un-blurred focused photographs in the field.

Image analysis – one or more observers with ability to distinguish the required categories of benthic cover, and past experience in coral monitoring and image analysis.

3.1.6. Background data

Compile the literature and results of past monitoring, surveys and research projects in the study are, and build up a narrative of coral reef health and any changes over that time. Construct timelines for as long as possible of the major benthic cover types in the table above (hard coral, soft coral, algal types, etc.)

Robust recovery, through recruitment and growth of branching and plating coral colonies, on a previously impacted reef By – Jerker Tamelander, IUCN

3.2. Coral community composition

3.2.1. Objective

Coral community structure can give insight on current status, past threats and future changes, from growth form to genus level.

3.2.2. Indicators

2.1 Rank abundance/diversity of coral community.

3.2.3. Methodology

Proportional abundance of all genera at a site is estimated on a five-point scale. This is done towards the end of the dive when an overall impression of the sampling site has been made, and the relative abundance of genera can be estimated. Additionally, it may be useful to update the numbers on the boat immediately following the dive.

Codes		***Class***	***Explanation***	***Numerical (approximate)***
D	5	Dominant	Dominate the coral community and/ or structure of the site	>30% of coral cover
A	4	Abundant	Visually abundant and seen in large numbers. Co-dominate the site	10-30% coral population by number or area and/or large number of colonies (>100) seen/inferred in the immediate area of the site (2500 m^2)
C	3	Common	Easily found/seen on site, but not dominant in any way	>1% of coral population by number or area and/or >20 colonies seen/inferred in the immediate area of the site (2500 m^2)
U/O	2	Uncommon/ Occasional	Not easily found, but several individuals seen or can be found by dedicated searching.	<10 colonies seen/inferred in the immediate area of the site (2500 m^2)
R	1	Rare	Found by chance occurrence or only 1 or 2 found by dedicated searching.	<2 colonies seen/inferred in the immediate area of the site (2500 m^2)

Seventy seven coral genera are listed below with three-letter codes used in the datasheets and illustrations. The 3-letter codes are based on the first 3 letters of the genus name when possible. Where this leads to duplicates a combination of the dominant letters of the name is used that also preserves the sort order of genera by full name and by the code.

Genus	***code***	***Genus***	***code***	***Genus***	***code***	***Genus***	***code***
Acanthastrea	aca	*Distichopora*	dis	*Leptoseris*	les	*Pocillopora*	poc
Acropora	acr	*Echinophyllia*	eph	*Lobophyllia*	lob	*Podabacea*	pod
Alveopora	alv	*Echinopora*	epo	*Madracis*	mad	*Porites*	por
Anacropora	ana	*Favia*	fat	*Merulina*	mer	*Psammocora*	psa
Anomastrea	ano	*Favites*	fav	*Micromussa*	mic	*Sandalolitha*	san
Astraeosmilia	asm	*Fungia*	fun	*Millepora*	mil	*Scolymia*	sco
Astreopora	ast	*Galaxea*	gal	*Montastrea*	mon	*Seriatopora*	ser
Australomussa	aus	*Gardineroseris*	gar	*Montipora*	mtp	*Siderastrea*	sid
Barabattoia	bar	*Goniastrea*	gon	*Moseleya*	mya	*Stylaster*	sta
Blastomussa	bla	*Goniopora*	gop	*Mycedium*	myc	*Stylocoeniella*	stc
Caulastrea	cau	*Gyrosmilia*	gyr	*Oulophyllia*	oul	*Stylophora*	sty
Coeloseris	coe	*Halomitra*	hal	*Oxypora*	oxy	*Symphillia*	sym
Coscinaraea	cos	*Heliofungia*	hef	*Pachyseris*	pac	*Trachyphyllia*	tra
Ctenactis	cte	*Heliopora*	hep	*Parasimplastrea*	par	*Tubastrea*	tub
Culicia	cul	*Herpolitha*	her	*Pavona*	pav	*Tubipora*	tup
Cycloseris	cyc	*Heteropsammia*	het	*Pectinia*	pec	*Turbinaria*	tur
Cynarina	cyn	*Horastrea*	hor	*Physogyra*	phy	*Zoopilus*	zoo
Cyphastrea	cyp	*Hydnopohora*	hyd	*Platygyra*	pla		
Diaseris	dia	*Leptastrea*	lep	*Plerogyra*	plg		
Diploastrea	dip	*Leptoria*	leo	*Plesiastrea*	pls		

Datasheet instructions – a datasheet with three-letter codes for each genus likely to be found in the area is needed. For clarity, the datasheet should exclude genera DEFINITELY NOT expected to be found in the region, but it is important to INCLUDE ALL LIKELY genera, so that after the dive, some genera that were seen but might not have been recorded are entered as present. The datasheet should have space for additional notes on any dominant/abundant/rare species.

Statistics from this dataset include:
- Genus richness, diversity and rank abundance
- Multivariate analysis and site association by coral genus composition
- Assessment of the target genera as representative of the site
- Diversity/dominance of coral genera at the site

3.2.4. Materials

Wet	***Dry***
datasheet	

3.2.5. Observer skills

A single observer, familiar with coral identification at least to the genus level and with broad experience in observing corals in the field. Ability to identify >90 % of coral genera at a site with ability to make notes/photographs and confirm identifications of unknown corals from ID guides.

3.2.6. Background data

Compile historical data on coral diversity and relative abundance for the study area and surrounding region, noting any changes in composition from any cause.

Large coral colonies may fall both in an outside the belt transect, requiring a decision by the observer to include them or not. Further, the observer often has to decide when fragments clearly of the same genet function as one single large colony (e.g. here) as opposed to separate individual smaller colonies.
By – Cheryl-Samantha Owen, Save Our Seas Foundation

3.3. Coral size classes and population structure

3.3.1. Objective

To collect data on coral community structure including recruitment and colony sizes of key genera dominant in the local area and representing different functional groups of corals.

3.3.2. Indicators

- Size class distributions (graphic), median and maximum size (index) by genus and overall
- Size class structure (densities, diversity, histogram, curve, median, mode, breadth, etc)
- Recruitment and small-colony survivorship (densities, diversity, survivorship)
- Recruitment rate – number of colonies in size class 1
- Recruit survivorship – ratio of size class 2 to 1
- Ratio of susceptible: intermediate: resistant genera (groups above, and defined by data set)
- Comparison of maximum colony size among sites

3.3.3. Methodology

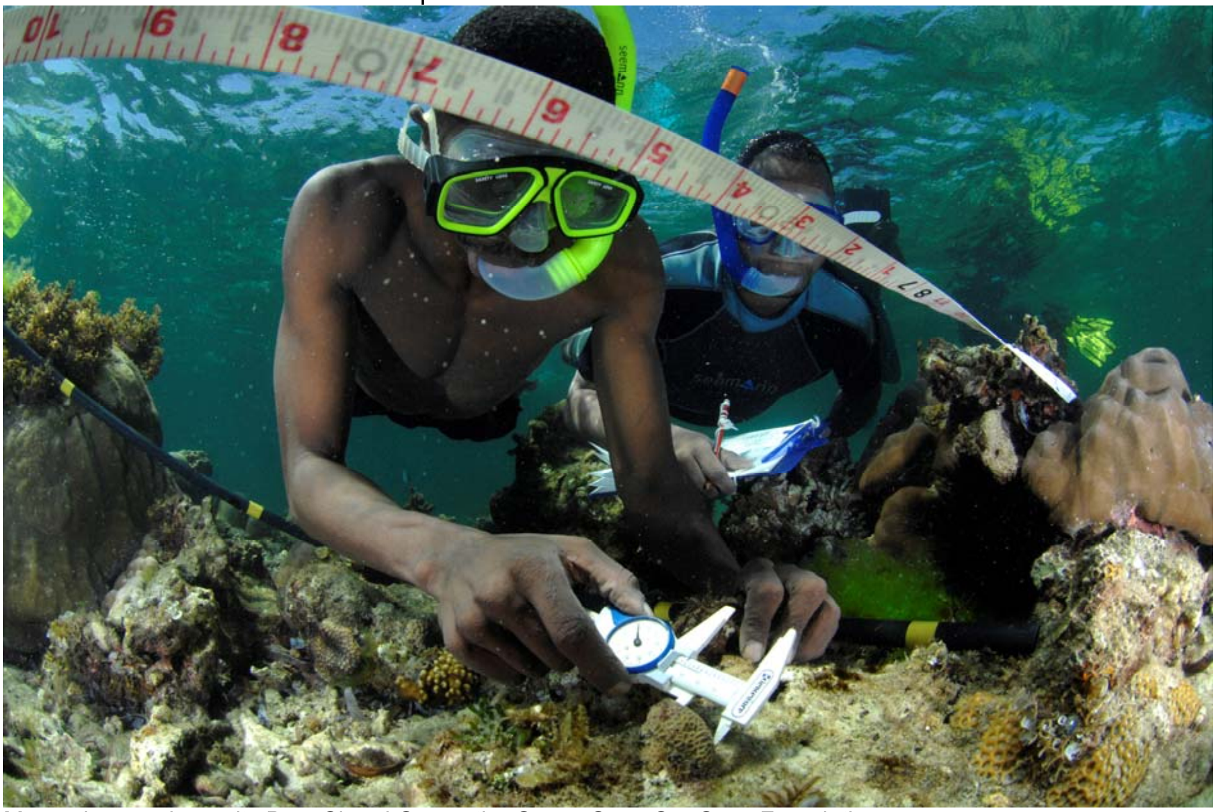
Data is collected within transects, for size class and recruitment, and at the overall site level, for maximum sizes of corals.

3.3.3.1. Size class and recruitment

A belt transect 25 m long and 1 m wide is used to record the number of colonies in targeted genera, for colonies larger than 10 cm. Sampling for corals smaller than 10 cm is done using six 1 m^2 quadrats located along the transect, either located haphazardly along the transect, or at fixed intervals (e.g. at 0, 5, 10, 15, 20, and 25 m).

Only colonies whose center lies WITHIN the transect are counted – large colonies with their center outside the transect must be ignored. A 1 m stick can be used to help guide estimation of transect width, held out in front as the observer swims down the transect. It can also be placed on the bottom at right angles to the transect line to mark the 1m^2 quadrats.

Size classes are listed in Table 3.1. The 1 m stick can also be marked at 5, 10, 20, 40 and 80 cm to help guide size estimation of large colonies in the transect, and the top of the slate at 2.5, 5 and 10 cm to assist with small colonies in the quadrats.



Measuring coral recruits By – Cheryl-Samantha Owen, Save Our Seas Foundation

Size classes for coral measurements.

Size classes (cm)	***Sampling method***	***Aids to sampling***	***Observers***
(1) 0-2.5 (2) 3-5 (3) 6-10	Recorded in six 1 m^2 quadrats per transect, at 0, 5, 10, 15, 20 and 25 m.	2.5, 5 and 10 cm marks at top of slate; 5 and 10 cm marks on 1 m stick	A single individual can do both. If a paired buddy team, one can do the quadrats the other the transect.
(4) 11-20 (5) 21-40 (6) 41-80 (7) 81-160 (8) 161-320 (9) > 320	Recorded in 25*1 m belt transects	10, 20, 40 and 80 cm marks on 1 m stick. For larger, use multiples of 1 m stick, or divisions on transect line.	

Selected general are recorded, as sampling all genera requires significantly greater time, and increases errors in identification particularly for small and rare colonies, and for inexperienced observers. Selected genera should number about 15-20 and cover a range of bleaching resistance from low to high, and may differ from one study region to another due to different relative abundance of corals. However within one region (e.g. western Indian Ocean) or under one institution it is helpful to use the same set of genera to enable detailed comparisons among sites. Selected genera must be abundant/typical ones to ensure a reasonable number of colonies are sampled – scoring many genera with only few colonies will not be useful for constructing size class distributions. If the abundance of corals locally is not well known, then some preliminary surveys to identify the abundant/common genera is necessary to select appropriately

Coral genera selected for Western Indian Ocean locations:

Low	***Intermediate - faviids***	***Intermediate - other***	***High***
Acropora *Montipora*	*Echinopora* *Favia*	*Fungia* *Galaxea*	*Porites* (massives, non-branching)

Pocillopora *Seriatopora* *Stylophora*	*Favites* *Platygyra*	*Hydnophora* *AcanthastreaLobophyllia* *Porites* (branching) *Coscinaraea*	*Pavona* *Astreopora*

The length (area) of transect sampled will be dependent on the complexity of the benthic community. Ideally, four 25 m transects should be collected from each site, though less 2 might be possible, depending on observer experience. Once practised, a diver should be able to record two full transects in one dive, so two observers can record 4 transects.

Because of variability in site characteristics and observer efficiency, a full transect or all 6 quadrats may not completed. The total distance surveyed, and number of quadrats, must be recorded to allow for this so that partial transects/quadrats can be analyzed.

3.3.3.2. Maximum size of corals

For each site, the maximum size of coral colonies is recorded in two ways:

1) *For the selected genera* – completion of the replicate transects, record the maximum size of colony seen ANYWHERE in the site, by writing an “L” into the appropriate table cell in the datasheet (e.g. if the largest *Acropora* is a table 2.5 m in diameter, write an “L” into the 1.6-3.2 m size class cell).

2) *For all corals* – in the site as a whole, record the 3 largest colonies at the site, of any genus/species, estimating the size, and identity (genus/species) as possible).

Datasheet instructions – this datasheet has space for two transects on each side of the paper. Large colonies are entered in the top section, and small colonies in the bottom. A scoring system, e.g. in groups of 5 (~~IIII~~), is most efficient in the field, and the number of colonies in each table cell added up during transfer to the computer. Genera are not pre-listed for small colonies as there is high variability in occurence so enter these as they are seen. A space is given at the top of the transect and quadrat fields for the length of transect and number of quadrats – if a transect cannot be completed it is still worthwhile to collect a partial dataset, and the length of the transect used to standardize to a fixed area. The largest colony at the site for each genus (not necessarily inside the transects) is indicated by an “L” in the relevant table cell (for only one transect, if two are recorded at each site).

3.3.4. Materials

Wet	***Dry***
transect line, 25 m (one per data collector) 1m ruler/stick marked at 10, 20 , 40 and 80 cm to help guide size estimates slate, marked along its top with 5, 10 and 20 cm to help guide size estimates datasheet	

3.3.5. Observer skills

Two observers, familiar with coral identification at least to the genus level for common taxa. Should be able to distinguish known from unknown genera, and to identify genera down to small sizes of 2-3 cm and if possible less. Experienced with benthic monitoring, such as LIT or using photographs.

3.3.6. Background data

Compile any past data on coral recruitment and sizes, though it is likely to be limited. Also, compile information on any extreme events (e.g. cyclones, floods) that may have caused high mortality to all or specific size classes or taxa of corals, to help interpret size class distributions.

3.4. *Coral condition and threats*

3.4.1. Objective

To collect data on coral threats including bleaching, disease, predation and other factors directly affecting corals.

3.4.2. Indicators

- Bleaching prevalence
- Disease prevalence
- Predation prevalence
- Urchins, COTs and other threats

3.4.3. Methodology

Using the same belt transect as the size class samples, the incidence of threats is noted for all colonies, including those not in the targeted genus list.

The coral threat observer should work the transect either following the size class observer or from the other end, to ensure not getting in each other's way. If the incidence of threats is low enough that the observer is finished with the transect before the size classes are completed, then collect the same data in a random swim area around the transects, the data being separated from that from within the transects.

Data to be recorded in coral condition surveys.

Related to:	Taxa	Data
Coral	Genus/species and size class	Percentage of colony pale (colour card level 2) and/or bleached (colour card level 1) and/or dead. All colour card (levels 3 and greater are classed as "normal". Presence of disease or other clear condition affecting the colony
Threat	Eroding sea urchins, crown of thorns, *Drupella*, other threats.	Number of individuals in belt transect (subsample if density is high) and number in general swim over study site.

Crown-of-thorns seastars, *Acanthaster plancii*, devouring an *Echinipora* colony. By – Jerker Tamelander, IUCN

3.4.4. Bleaching and mortality

Bleaching and mortality levels by colony can be recorded at different levels of precision. The most basic level is summarized in the table below, from Oliver et al. (2004), below but if observers are experienced researchers, more detailed data can be collected. CoralWatch colour cards can be used to standardize among observers(Siebeck et al. 2006) can be used to standardize among observers. However it may only be useful to record colour shades 1 and 2, which represent bleached and pale respectively; in many instances colour shades 3- may be considered as “normal“ for the corals, so not useful in this case to record them individually.

Colour categories from Oliver et al. 2004.

Category	***Description***	***Colour cards***
0	No bleaching evident	All shades 3-6
B1	Partially bleached (surface/tips); or pale but not white;	Shade 2
B2	White	Shade 1
B3	Bleached + partly dead	Shade 1
D	Recently dead	

Examples:

- for a *Porites* massive colony 30 cm in diameter, with 50% of the colony pale, the record would be *Por(mas) B1*. A more experienced data collector could record this as *Por(mas) C5 p50%*. (C5 for size class 4).
- for a *Stylophora pistillata* colony 15 cm in diameter, 60 % bleached, 40% dead), the record would be *stypis* B3. A more experienced data collector could record this as *stypis C4 bl60 d40*.

3.4.5. Coral diseases and other conditions

Disease and other conditions to be recorded; need to be confirmed for each site, may include the list below (sources: Disease Working Group (CRTR), McLeod(2007):

DISEASES:
- TUM-Growth anomalies/tumours
- SEB-Skeletal eroding band/skeletal eroding disease – powdery/eroded skeleton
- BBD-Black Band Disease (BBD)
- BrD - Brown/other colour bands,
- WBD - White Band Disease
- WP - White Plagues/Syndromes
- WS - Spots – white spots (*Porites*),
- PS - pink/purple spots/lines (*Porites*),
- BP - Blotch/spot disease – large dark spots/patches

OTHER:
- Possible other conditions for identification to be confirmed for each site, may include:
- Predation scar – parrotfish/other excavating grazer
- Predation scar - COTS
- Tubeworm infestations
- etc.

Where more detailed disease work is possible, or the team has a collaboration with external groups, then follow established/more detailed protocols for photographing/document/collecting disease conditions observed.

For the same two examples as listed above, with the *Porites* colony showing parrotfish scars and the *Stylophora* colony black band disease, the records would be:
- *Por(mas) B1* COTs, or *Por(mas) C5 p50%* COTs
- *stypis* B3, BBD, or *stypis C4 bl60 d40 BBD*

3.4.6. Other threats

This area primarily focuses on invertebrate predators and threats to corals, that can have an impact on community structure when at moderate to high abundances. These include:

Crown of thorns seastars (COTs), *Acanthaster planci*. At levels of > 1-2 individuals per transect predation impact is significant, and both individuals and predation scars should be counted.
- Cushion star, *Culcita*. Can also have an impact on corals through predation, though not as high as COTs.
- *Drupella* – predatory snail, often found on branching corals. Generally not possible to count, but can be recorded as number of colonies infested and range of density.
- Eroding sea urchins – large-bodied sea urchins, in particular the genera *Diadema*, *Echinothrix* and *Echinometra* (the latter may be at very high densities and cryptic, so subsampling may be necessary).

Datasheet instructions – a blank datasheet is given, as the presence of any condition may be low at any one site, so the same sheet might be used over multiple sites. Make sure to clearly label the site, date and transect # for each set of data. Alternatively, using a disease/condition datasheet already developed for the area will ensure compatibility with broader datasets. For transects with no disease/bleaching/condition noted, indicate this with a blank, to document the site was surveyed, but no condition seen.

Statistics from this dataset include:
- For targeted coral genera/species, prevalence of bleaching/disease (ie. ratio of affected : total population)
- For non-targeted coral genera/species, incidence of bleaching/diseased (ie. number affected)
- Number of colonies showing each condition, and total recorded
- Prevalence of each condition - proportion of colonies recorded with a condition compared to number of colonies in the transect.
- Overall levels of each condition recorded as a number and prevalence.

3.4.7. Materials

Wet	*Dry*
transect line, 25 m (use existing from coral size class observer)	
Datasheet	
checklist of disease/condition codes (on datasheet)	

3.4.8. Observer skills

A single observer, familiar with coral identification at least to the genus level and with broad experience in observing corals in the field. Ability to distinguish conditions such as scars from different sources, bleaching and 'disease' conditions.

3.4.9. Background data

Compile any past data on coral bleaching or diseases, as well as on land- or sea-based stresses or vectors for bleaching or disease.

3.5. Fish community structure and herbivory

This section improves on standard underwater visual census (UVC) of fish by focusing on herbivore functional groups, adapted from Green et al. (2009) to include other functional groups of fish.

3.5.1. Objective

To collect data on herbivore and other functional groups of fish that exert top-down control on phase shift dynamics on coral reefs.

3.5.2. Indicators

- Number of fish species, overall and by functional groups.
- Abundance/density of fish overall, by functional groups and species.
- Composition of fish population by functional/trophic groups.

3.5.3. Methodology

The method focuses on censusing fish at sufficient resolution to allow analysis of biomass and by functional group. The level of detail needed for different functional groups various from species to family level, and equations for calculating biomass from length can vary by species. If possible therefore, species-level sampling of fish is ideal. However, this is rarely possible, so several compromises are presented below.

3.5.3.1. Functional groups

With a focus on assessment of the resilience of reef communities, fish sampling should be focused on the major functional groups that we currently understand to exert top-down control on reef dynamics and may be indicators of resilience (in the coral community). These are:

- Herbivores – exert the primary control on coral-algal dynamics and are implicated in determining phase shifts from coral to algal dominance especially in response to other pressures such as eutrophication, mass coral mortality, etc. E.g. parrotfish (*Scaridae*), surgeonfish (*Acanthuridae*).
- Piscivores/carnivores – top level predators, they exert top-down control on lower trophic levels of fish, are very vulnerable to overfishing, and good indicators of the level of anthropogenic disturbance (fishing) on a reef. E.g. sharks, groupers (*Serranidae*), jacks (*Carangidae*).
- Scavengers/generalists – second-level predators with highly mixed diets including small fish, invertebrates and dead animals, their presence/absend is a good indicator of anthoropogenic disturbance (fishing). E.g. snappers (*Lutjanidae*), emperors (*Lethrinidae*), sweetlips (*Haemulidae*).
- Obligate and facultative coral feeders – the relative abundance of these groups are a secondary indicator of coral community health. E.g. butteflyfish (*Chaetodontidae*) and some filefish (*Monacanthidae*).

- Sessile invertebrate feeders – feed on coral competitors such as soft corals and sponges, their relative abundance may be a secondary indicator of abundance/stability of these groups and of a phase shift. E.g. angelfish (*Pomacanthidae*).
- Planktivores – resident on reef surfaces, but feed in the water column. Their presence/absence may be related to habitat for shelter and water column conditions. E.g. some triggerfish (*Balistidae*), fusiliers (*Caesionidae*).
- Detritivores – feed on organic matter in sediment and on reef surfaces, their relative abundance may be an indicator of eutrophication and conditions unsuitable for corals. E.g. goatfish (*Mullidae*).

For each application, the history of fish surveys in the area should be considered, and adjusted to enable construction of functional groups for analysis here. For example, if family level surveys have been done, then some families have to be split into genus/species sub-groups to distinguish different functional/trophic groups – e.g. triggerfish split into planktivores and benthic invertebrate feeders, etc. See below for how this is done for herbivore functional groups.

An indicative list of families, some of them with multiple functional groups (e.g. *Balistidae*), is given below, to be combined with the list of herbivore functional groups for surveys.

Group/family	***English***	***Notes***
Piscivores/scavengers		
Carangidae	Jacks/trevallies	
Haemulidae	Sweetlips	
Lethrinidae	Emperors	
Lutjanidae	Snappers	
Mullidae	Goatfish	
Serranidae	Groupers	
Invertivores		
Balistidae	Triggerfish	Invertivores, all on the benthos
Pomacanthidae	Angelfish	Invertivores/sessile
Labridae	Wrasses	Invertivores
Obligate coral feeders		
Monacanthidae	Filefish	*Oxymonacanthus* only
Chaetodontidae	Butterflyfish	Coral obligates/indicators, by species
Detritivores		
Acanthuridae		Detritivores - *Ctenochaetus*
Planktivores		
Caesionidae	Fusiliers	Planktivores
Balistidae	Triggerfish	Planktivores, all in the water column
Acanthuridae	Unicornfish	Some > 20 cm; by behaviour in water column

3.5.3.2. Herbivore functional groups

Green et al. (2009) distinguish 6 herbivore functional groups: large excavators, small excavators, scrapers, grazers, browsers and grazers/detritivores. Each plays an ecological role in coral reef resilience. The composition of these functional groups varies across taxonomic scales; in some cases whole fish families belong to one group but in many cases genera and even species within the same family can fall into different groups. In some cases functional group changes with size or age of the fish. Fish families that are herbivores include the *Acanthuridae* (surgeonfish), *Ephippidae* (batfish), *Kyphosidae* (chubs), *Pomacanthidae* (angelfish), *Scaridae* (parrotfish) and *Siganidae* (rabbitfish).

Functional groups of herbivorous fishes.

Functional group	***Taxonomic groups***	***Function and notes***
Large excavators Humpheaded parrotfish – large individuals (>35 cm)	*Bolbometopon*, *Chlorurus microrhinos*, *C. frontalis* and *Cetoscarus bicolour*. All humpheads > 35 cm	Bioerosion. They take fewer, larger, deeper bites, remove more of the substratum with each bite, and play a key role in bioerosion.
Small excavators Humpheaded parrotfish – small individuals (<35 cm)	As above and other *Chlorurus* species (*C. bleekeri* and *C. sordidus*; All humpheads <35 cm)	Bioerosion. Take more, smaller, shallower bites, and remove less of the substratum with each bite.
Scrapers Other parrotfish	*Scarus* and *Hipposcarus*	Bioerosion, colonization surfaces. Remove algae, sediment and other material by closely cropping or scraping the substrate.
Grazers Small rabbits, many surgeons	Small rabbitfish (<20cm), all *Centropyge*, all *Zebrasoma,* most *Acanthurus* (excl. planktivores/ringtails).	Algal control. Remove epilithic algal turf from the reef substratum, but do not scrape the surface, prevent coral overgrowth and shading by macroalgae.
Browsers Unicorns, chub, batfish, large rabbits, Calotomus	Chub, batfish, large siganids (> 20cm), and parrotfish of genus *Calotomus, Leptoscarus*. Unicornfish - all sizes of *N. brachycentron, N. elegans, N. lituratus, N. tonganus* and *N. unicornis*, Unicornfish - <20cm of *N. annulatus, N. brevirostris, N. maculatus, N. mcdadei*, and *N. vlamingii*	Algal control. Feed on macroalgal fronds, reduce coral overgrowth and shading by macroalgae.
Grazers/detritivores Ringtail surgeons	Ringtail surgeonfish - *Acanthurus blochii, dussumieri , leucocheilus, maculiceps, nigricauda, olivaceus, pyroferus, A tristis* and *A xanthopterus*.	Algal/sediment control. feed on a combination of algal turf, sediment and some animal material similar role to grazers, remove macroalgae before it can become established.

The two families that are the most complex in monitoring heribovrious fish are the *Scarids* (parrotfish) and the *Acanthurids* (surgeonfish). All *Scarids* are herbivores, though they are split between four functional groups – excavators (large and small), scrapers and browsers. *Acanthurids* are more complex, as they are split between three functional groups (browers, grazers and grazers/detritivores), and some *Acanthurids* fall into other functional groups, namely planktivores and detritivores as follows:

- Planktivores: unicornfish (*Naso*) larger than 20 cm (*N. annulatus, N. brevirostris, N. maculatus, N. mcdadei*, and *N. vlamingii*), some *Acanthurus* species (*A. albipectoralis*, *A.mata*, *A. nubilus* and *A. thompsoni*) and the monospecific genus *Paracanthurus.* Planktivorous surgeonfish can be excluded by behaviour (surgeons swimming/schooling in the water column not on the benthos), rather than by taxonomy, so can be relatively easily excluded visually.
- Detritivores: *Ctenochaetus*. This is only common in shallows, where it may be in large schools.

A number of other families of herbivorous fishes are not included in the list above for the following reasons:

- Small, cryptic families (blennies and gobies) - not amenable to visual census techniques, and low contribution to ecosystem resilience.
- Damselfishes - small, and hard to identify, and wide variety of diets.
- *Monacanthidae* and *Balistidae* – some may also be herbivores, but unconfirmed.

For logistical reasons, Green et al. (2009) recommend simplifying the range of herbivore functional groups. Considering that some functional groups are distinguished on the basis of size (thus can be assigned during analysis, not in the field), and the relative importance of parrotfish and surgeonfish and their different functional groups. Two levels of resolution are suggested for surveys, depending on the expertise of the observer.

Bumphead parrotfish, *Bolbometopon*, the large excavators on the reef. By – Jerker Tamelander, IUCN

Recommended level of identification for fish herbivore functional groups.

Family	*English*	*Functional grp*	*Level of identification*	*Notes*
Scaridae	Parrotfish	Excavators Scrapers Browsers	Humpheads - *Bolbometopon, Cetoscarus, Chlorurus* *Scarus, Hipposcarus* *Calotomus, Leptoscarus*	If these cannot be distinguished, then all >35 cm are excavators, and all < 35 cm are scrapers
Acanthuridae	Surgeonfish	Browsers Grazers/ detritivores	Unicorns (*Naso*) Most *Acanthurus, Zebrasoma*	Some Naso excluded by size, all planktivores could be excluded by behaviour/ location in water column
Siganidae	Rabbitfish	Browsers/Grazers -detritivores	Whole family	Differentiated by size
Kyphosidae	Chub	Browsers	Whole family	
Ephippidae	Batfish	Browsers	Whole family	
Centropyge	Angelfish	Grazers-detritivores	Whole family	

Simplest level of identification for fish herbivore functional groups.

Functional group	*Level of Identification*	*Notes*
Excavators	Bumpheads/parrotfish > 35 cm	
Scrapers	All parrotfish < 35 cm	Combines scrapers with small excavators – their function is most similar than other groups.
Browsers	Rabbitfish, Chub, Batfish, small unicornfish	Combines small rabbitfish from grazers, and loses some parrotfish. Large unicornfish can be excluded by size, and planktivorous unicornfish by behaviour.
Grazers/detritivores	All surgeonfish except unicornfish	Combines grazers with grazers/detritivores. Strongly simplifies surgeonfish identifiction.

As a first exercise for each region, a full listing of herbivorous species and their allocation to each functional group must be done, as in the annexes at the end of this section, and if possible checked by an expert before starting the surveys. Underwater, some unlisted species may be seen, which need to be added to the list and verified.

3.5.4. Sampling

Sampling combines one long swim, to maximise sampling of the large mobile fish (e.g. bumphead parrots) with 3 replicate transects for density estimates of fish.

3.5.4.1. Long swim

The long swim consists of a 20 minute timed swim at a standardised swimming speed parallel to the reef axis. The length of the swim should be standardized as far as possible to 400 m, though in some conditions it may not be possible to go this far. Record the approximate length of each swim, and take into account currents, etc in estimating the distance swum. The area sampled should be approximately 20 m wide, or 10 m on either side of the observer, though it might be less due to visibility constraints. Document any departures from the standard length and width.

Only the largest size classes of key species in the different functional groups should be recorded, i.e. from 30 or 35 cm and up, and the size of each fish (or size class in 10 cm bins if many fish are encountered), recorded. A sample list of key species is indicated here, though this should be tailored to the local situation.

Functional group	*Fish*
Predators	Sharks Large groupers: *Epinephelus tukula* *E. caeruleopunctatus* *E. multinotatus* Other Epiniphelidae *Cephalopholis* sp.
Scavengers	*Lutjanus bohar*
Herbivores	*Bolbometopon spp.* *Chlororus spp.* *Scarus spp.*

3.5.4.2. Transects/point counts

Transects are undertaken using standard 50*5 m belt transects for the remainder of target species (the transect length should always be 50 m, with fewer replicates if restricted by time). If they occur in the transects, include the larger individuals previously counted in the long swims. Lay transects consecutively along the depth contour parallel to the reef axis, separated by at least 5 to 10m from the end of the previous transect. Swim along the transect counting and estimating the size (TL in cm) of all species.

The transect laying technique may depend on the number of observers. With a single observer fish can be sample in the first pass WHILE the transect is being laid, and small fish in the second pass while it is being taken up. Adapt the technique to the observers' experience.

Where point counts have been used historically, it may be more useful for analysis to continue their use here, rather than applying transects. Point counts of 7 m radius (150 m^2) are the easiest to implement. With two divers sampling separate circles, up to 10 can be recorded following the end of the long swim, or in some cases can be conducted intermittently during the long swim. Local conditions will determine the time to spend on each point count (5-10 minutes), and taxa may have to be counted in individual 'sweeps' of the circle to minimize increasing numbers of fish during longer counts when new fish may swim into the circle.

A minimum size for inclusion of 10 cm should be used, except for *Centropyge*, where 5 cm should be used. 5 cm size classes should be used (i.e. 5-10, 10-15, 15-20 cm, etc).

If two depth zones are sampled (e.g. 5 and 10-12 m), these may be very close together where the reef slope is steep. In this case the long swim counts for BOTH depths together. Alternatively, if the reef is homogeneous, then shift the deep and shallow samples along the reef to ensure the long swim samples do not overlap.

Datasheet instructions – some additional space is given for genera/species note written on the datasheet.

3.5.5. Materials

Wet	*Dry*
transect line, 50 m (may be useful to have two, one for each buddy in a team) point count – central marker and 7 m radial line Datasheet	

3.5.6. Observer skills

One or two observers, familiar with UVC of fish and ability to distinguish major genera and key species of fish in the field. Ability to recognize targeted species of fish from a list and with prior preparation from field ID materials. Size and distance estimation.

3.5.7. Background data

Compile past data from UVC of fish and any herbivory studies. Additionally, fisheries data that shows effort levels, catch trends and composition, particularly if target species have changed over time and moved down the food chain.

3.6. Site resilience factors

3.6.1. Objective

To collect data on site-level factors influencing the resistance and resilience of corals to thermal stress.

3.6.2. Indicators

- Estimated level of each resistance/resilience indicator (5-point scale)

3.6.3. Methodology

Resilience indicators are estimated using two approaches – *in situ* estimation based on recognition of key features, and desk-study, based on reference material (including the literature, maps, charts, reports, etc), local knowledge and available data. Some indicators are quantified using one approach, some may be by both, where information from one approach may modify that from the other. The underwater datasheets include spaces for each factor, though some may be quantified only by desk study.

3.6.4. Data sources

In situ observation – during a field survey, levels are scored based on a detailed criterion table. The criterion table must be customized to each area of application, and be held consistent for an entire survey. A 5-point scale is used (1-low, 5-high) for each indicator, and scored for each sample site/zone. Indicators are scored after the mid-point of the dive to allow time for familiarization with the site. Levels may be adjusted during or after the dive, and through discussion with other team members. In the water, the observer should go through each group of indicators, spending up to 5 minutes on each group, as necessary. A comments field for each indicator is given to facilitate documentation of the indicator level chosen.

Reference sources – where information from ongoing datasets (e.g. of temperature), the literature, reports, maps, charts, local knowledge or key informants can be used, parameters related to each indicator should be quantified. As far as possible this should be done in real units, to be converted to a 5-point scale during preliminary stages of analysis. For example, fishing pressure may be obtainable from catch data, underwater monitoring data, local knowledge (particularly on individual-site basis), or by proxy by distance from the nearest fishing village. Likewise, distance to deep water can be measured directly from charts, either by straight-line distance, or where known by upstream-downstream distance.

3.6.5. Approach

Indicators are grouped into several clusters, reflecting major ecological components shown by research to date to be important in resistance/resilience of coral reefs to climate change:

- benthic cover, principally of hard and soft corals, algal types and substrate condition (rubble);
- physical/environmental parameters conferring resistance or resilience, relating to cooling/flushing, shading/screening and acclimatization of corals;
- coral population and community indicators of resistance or resilience, relating to coral condition and population structure;
- coral associates with positive or negative impacts on corals;
- fish community structure, particularly herbivores;
- anthropogenic factors that affect resistance or resilience, relating to water quality, substrate condition and fish/herbivore populations.
- connectivity and genetic relatedness, affecting recolonization and risk-spreading across multiple locations.

3.6.5.1. 5-point scale

A semi-quantiative scale (Likart) of 1-5 is used for estimation of all the indicators. Where an indicator can be quantified directly (e.g. visibility in meters, slope in degrees) it is recorded directly, and converted to a 5–point scale during analysis. The 5-point scale was selected to facilitate estimation of minimum (1), maximum (5) and moderate (3) level for each indicator for the region of application, and intermediate levels of low (2) and high (4).

Note that two separate approaches can be taken when scoring indicators from 1 to 5:

- where 1 designates low/poor/negative conditions for the variable itself, and 5 designates high/good/positive conditions. In this case, high macroalgal abundance would be scored as '5' and low abundance as '1'.
- where 1 designates low/poor/negative conditions for corals and 5 high/good/positive conditions. In this case, high macroalgal abundance would be scored as '1' and low abundance as '5'.

For final analysis, all indicators will be converted to a common scale to enable simple addition (i.e. option b), but during fieldwork, the most direct and simple approach is to score using option a. This must be explicitly noted for ALL indicators.

It is essential for the observer recording resilience indicator levels to be fully comfortable with the rationale behind the scaling. A detailed description of each level of the 5-point scale for each indicator is included as background material, and must be reviewed and customized for each region of application. For example the location in a region with maximum wave energy should be designated as 5 on the scale – in one region this might be a reef front that experiences 2 m wind-waves during storms, in another region this might be a reef front that experiences 4 m ocean swells during a particular season. Scaling for between-region comparisons will be dealt with based on the levels set in each region's definition table, at a later date.

3.6.5.2. Spot vs. continuous measurements

Variables like temperature and visibility are estimated during the dive, however because of seasonal and annual variability must be analyzed cautiously and in the context of background data. Where possible, continuous measurements, such as in situ temperature recorders, should also be used. This is unlikely to be possible for all site, but a representative selection of sites should be selected according to local conditions and priorities. Spot measurements give some insight as to short-term differences between sites, such as in exposure to upwelling water, influence of storms and mixing events, etc.

3.6.6. Resilience indicators

The resilience indicators are presented in groups, which are maintained during analysis to relate to the key drivers of reef resilience. Further illustration of this rationale can be found in Obura and Grimsditch (2008).

3.6.6.1. Benthic indicators

These can be estimated on-site and/or be derived from more quantitative methods such as those used in monitoring and assessment programmes, e.g. line intercept transects, photo quadrats, etc. The advantages of estimating them with the other indicators is to ensure values are available for all sites. Estimated values can be replaced by more quantitative values where/when these are available. The disadvantage of estimated values relate to observer error in estimating percentages, however this is somewhat ameliorated by conversion to a 5-point scale for analysis with other indicators.

Variable	*Relevance*	*Quantification*	*Data source*
Hard coral	A primary indicator of reef health, hard corals are the main reef-building taxonomic group on coral reefs	estimate % cover	in situ
Soft coral	Common competitor to hard corals, and can indicate nutrient and wave energy conditions	estimate % cover	in situ
Fleshy Algae	A primary competitor and inhibitor of corals, and indicator of nutrient/bottom-up and herbivory/top-down controls.	estimate % cover	in situ
Turf Algae	A primary competitor and inhibitor of corals, and indicator of nutrient/bottom-up and herbivory/top-down controls.	estimate % cover	in situ
CCA	An indicator of suitable habitat for coral recruitment, and consolidation of reef framework.	estimate % cover	in situ
Rubble	An indicator of substratum integrity and suitability for coral recruitment and growth.	estimate % cover	in situ

3.6.6.2. Substrate and reef morphology

Stress to corals and recovery (i.e. recruitment, growth, etc) are strongly affected by substrate quality. The amount of rubble, measured under benthic cover estimates gives an indicator on the consolidation of the reef. Topographic complexity is important as it determines the amount of space available for fauna and flora to attach to, and the complexity of interaction between substratum and the water column. Sediment quality and quantity strongly affect the survival of benthic organisms, and in particular recruitment of larvae to benthic life stages.

Variable	*Relevance*	*Quantification*	*Data source*
Topographic complexity – micro	The surface roughness and small-crevice space on reefs affects recruitment of corals.	Estimation on 5 point scale of surface roughness, from smooth to complex 3-D spaces allowing light penetration but shelter from predators and sedimentation (e.g. in complex branching frameworks), Approx. 1-10 cm scale.	In situ
Topographic complexity – macro	The large scale structure of a reef, providing habitats for large and higher-trophic level mobile organisms (e.g. fish)	Estimation on 5 point scale of structure, from a flat pavement to complex 3-D reef slopes with spur/grooves, pillars, caves and large internal reef spaces. Approx. 1-5 m scale.	In situ
Sediment layer texture	Sediment grain size and sorting affects benthic organisms.	Estimation on 5 point scale, from large-size/carbonate sand grains at one end (good) to fine silty sediment with high terrigenous content at the bad end.	In situ, reference
Sediment layer depth	Depth of sediment layers on hard substrata, particularly in association with algal filaments/turf.	Estimation on 5 point scale, from no sediment on hard substrata to drifts of sediment and/or entrapment of sediment in algal filaments/turf that inhibit settlement.	In situ, reference

3.6.6.3. Cooling and flushing

The temperature of the surface skin of seawater that heats up and causes stress to corals may be reduced by a number of physical processes causing mixing with deeper cooler waters and/or by evaporative cooling. These factors may provide protection from and enhance resistance/tolerance of corals to thermal stress.

Variable	***Relevance***	***Quantification***	***Data source***
Temperature	Primary stressor for bleaching related to climate change.	Spot measurements with a thermometer allow basic comparisons among sites, but ideally need long term *in situ* records, and satellite data to infer differences among sites.	In situ, reference
Currents	Currents cause vertical mixing that may reduce surface temperatures, and can reduce coral stress by reducing boundary layer effects on coral metabolism.	Estimation on 5 point scale, informed by local knowledge and/or by 'typical' expectations of particular reef structures such as linear reef fronts, channels, etc.	In situ, reference
Waves (Exposure)	Wave energy causes vertical mixing, can reduce boundary layer effects on coral metabolism and increases oxygenation of water, enhancing coral metabolism. Exposure to weather events is expressed as wave energy to corals.	Estimation on 5 point scale, from minimum waves on sheltered/leeward reefs to maximum waves on reef crests. Increasing depth reduces the influence of wave energy, so is quantified under 'depth' not in this indicator. Exposure and wave energy are related, so one may be sufficient for estimation.	In situ, reference
Deep water	Proximity to deep water enables mixing with cold water by upwelling and waves, currents and exposure.	Estimation on 5 point scale, from immediate proximity at a vertical wall, to distant. Alternatively, distance to a deep contour (30/50 m) may be measured from charts.	In situ, reference
Depth of reef base	The depth of the base of a reef slope affects the potential for mixing of deep cool waters.	Actual depth of base of main reef slope. Along with "deep water" gives an indication of potential for upwelling/mixing of cooler water.	In situ, reference

3.6.6.4. Shading and screening

Thermal stress in corals is exacerbated by light stress, so factors that reduce light reaching corals can provide protection and/or enhance resistance/tolerance during coral bleaching events.

Variable	***Relevance***	***Quantification***	***Data source***
Depth	Basic zonation variable for coral reef and community structure, and for attenuation of temperature, light and other variables	In situ measurement, usually samples done in standard depth zones for analysis. Tidal variation important to be factored out, particularly where range > 2 m.	In situ
Visibility	Proxy for turbidity and attenuation of light levels at a site, a primary and synergistic stressor with temperature.	Horizontal visibility at the sampling depth, or improved with use of secchi disc (though not possible in shallow water). Where possible suspended particulates/ turbidity can be measured.	In situ, reference
Compass direction/ Aspect	The aspect of a reef slope affects the angle of incidence of the sun on the reef surface, and therefore radiation per area of reef/colony surface.	Compass direction of the reef slope. The 5 point scale will be determined based on compass direction and latitude, during analysis.	In situ
Slope	The angle of a reef slope affects the angle of incidence of the sun.	Estimated slope angle, in degrees. The 5 point scale will be determined based on the range of values, during analysis.	In situ
Physical shading	Shading of corals by reef slopes, pillars or above-water features (hills/cliffs/ rocks) can protect corals from stress.	Estimation on 5 point scale, with the maximum for full shading at noon by vertical wall/overhang.	In situ
Canopy corals	Shading of understory corals by canopy corals (tables, staghorn, plates, etc) can protect them from stress.	Estimation on 5 point scale, with the maximum for cover by canopy corals.	In situ

Partially bleached *Acropora* colony By – Jerker Tammerlander, IUCN

3.6.6.5. Extreme conditions and acclimatization

Resistance and tolerance to thermal stress is enhanced by acclimatization of adult colonies to their environment. Typically, acclimatization is most strongly expressed in varying and/or severe environmental conditions, and variation in one stress factor may enhance generalized resistance to multiple stresses.

Variable	***Relevance***	***Quantification***	***Data source***
Low tide exposure	Shallow corals exposed to the air at low tide experience frequent stress, and may be more resistant to thermal stress.	Estimation on 5 point scale, relevant only to very shallow corals.	In situ, reference
Ponding/pooling	Restricted bodies of water heat up more due to less mixing and greater residence times, and also enhance metabolic stress.	Estimation on 5 point scale, maximum for enclosed shallow bodies of water	In situ, reference

3.6.6.6. Coral condition

The current status of a coral community depends on past events and current conditions. This component estimates as best as possible the extent of past thermal stress/bleaching events (or other major mortality events), recovery to date and current bleaching, disease and mortality.

Variable	***Relevance***	***Quantification***	***Data source***
Bleaching	Current levels of coral bleaching.	Percentage of corals bleached.	In situ
Mortality-recent	Current levels of coral mortality.	Percentage of corals showing partial/full mortality.	In situ
Mortality-old	Levels of mortality from the past.	Degree of historic mortality evidenced by appearance of dead coral skeletons. Directly quantified, or as 5 point scale depending on ease of estimation.	In situ, reference
Recovery-old	Levels of recovery from the past mortality events.	Degree of recovery from old mortality, appearance of dead coral skeletons and regrowth/recolonization of corals since then, and knowledge on past mortality. Directly quantified, or as 5 point scale depending on ease of estimation.	In situ, reference
Disease	Levels of coral disease	Percentage of corals showing disease conditions.	In situ

Porites colonies exposed at low tide survive under extreme environmental fluctuations
By – Jerker Tamelander, IUCN

Acropora coral recruit By – Gabriel Grimsditch, IUCN

3.6.6.7. Coral population structure

The size class structure of coral populations can reveal evidence of past events and current recovery patterns. More detailed data on coral recruitment and size class distributions are collected in other components of the assessment method, however these estimates might provide useful information when these are not possible.

Variable	***Relevance***	***Quantification***	***Data source***
Recruitment	Recruitment of new corals is necessary for population recovery and injection of genetic variability.	Estimated number and genus of recruits/new corals < 2-3 cm, per m^2 of substrate.	In situ
Fragmentation	Asexual reproduction by fragmentation is an important strategy of propagation for many corals.	Estimated contribution of fragmentation in generating new colonies, and primary genera affected. 5 point scale based on evidence for partial mortality/fragmentation producing significant number of small to mid-sized corals (e.g. 5 – 20 cm)	In situ
Dominant size classes	The dominant size classes, by area, indicate the maturity and ecological stage of a community.	Estimation of dominance in the coral community by size class and genus of coral, indicating successional stage of the community.	In situ
Largest corals	The largest corals at a site indicate how long conditions have been suitable at the site, and the degree of environmental stability/ community persistence	The size in meters, and genus/species of the three largest colonies at the site.	In situ

3.6.6.8. Coral associates

The presence and number of coral associates are indicative of the health and maturity of the coral community, and influence of external factors. These variables are not primary indicators of reef resilience, so lower priority than others.

Positive associates

Variable	***Relevance***	***Quantification***	***Data source***
Obligate feeders	The abundance and diversity of obligate coral feeders are indicative of the health of coral colonies and complexity of interactions at a site.	Estimation on 5 point scale, from absent to high abundance/ diversity.	In situ
Branching residents	The abundance and diversity of fish and invertebrate residents in branching coral colonies are indicative of the health of coral colonies and complexity of interactions at a site.	Estimation on 5 point scale, from absent to high abundance/ diversity.	In situ

Negative associates

Variable	***Relevance***	***Quantification***	***Data source***
Competitors	The abundance and diversity of coral competitors are indicative of inhibiting factors to coral growth and recovery.	Estimation on 5 point scale, from absent to high abundance/ diversity	In situ
Bioeroders – external (urchins, nonfish)	The abundance and diversity of nonfish exernal bioeroders are indicative of inhibiting factors to coral growth and recovery	From transect/ quadrat counts or by estimation on 5 point scale, from absent to high abundance/ diversity.	In situ
Bioeroders – internal (sponges, worms, etc)	The abundance and diversity of internal bioeroders are indicative of inhibiting factors to coral growth and recovery	Estimation on 5 point scale, from absent to high abundance/ diversity	In situ
Corallivores (negative impact)	The abundance and diversity of corallivores (eg. COTs, *Drupella*) are indicative of additional mortality to coral colonies.	From transect/ quadrat counts or by estimation on 5 point scale, from absent to high abundance/ diversity.	In situ

Tube worms on *Lobophyllia* coral. At low densities these are seldom harmful but at high densities may impede coral growth and/or indicate poor conditions for corals By – Jerker Tamelander, IUCN

3.6.6.9. Fish functional groups - herbivory

Fish exert important top-down controls on benthic communities, and in the case of ecological recovery and resilience, herbivory has been shown to be particularly important. More detailed data on fish and herbivore groups should ideally be collected in other components of the assessment method, however these estimates might provide useful information when these are not possible.

Variable	***Relevance***	***Quantification***	***Data source***
Abundance & diversity of herbivores	Overall herbivore populations are critical for suppressing algal growth and its inhibiting effects on corals	Visual estimate of abundance/ diversity of herbivores	In situ, reference, long term
Eroders	Excavating/eroding herbivores exert strongest control on algal growth	Visual estimate of abundance/ diversity of excavators - *Bolbometopon*, *Chlorurus*	In situ
Scrapers	Excavating/eroding herbivores exert control on algal growth	Visual estimate of abundance/ diversity of smaller parrotfish.	In situ
Browsing	Browsing herbivores exert control on macroalgal fronds	Visual estimate of abundance/diversity of unicornfish/chubs/batfish/large rabbitfish	In situ
Grazing	Grazing herbivores exert control on epilithic turf algae	Visual estimate of abundance/ diversity of parrotfish and surgeonfish that crop algae	In situ

3.6.6.10. Connectivity

The degree of connectivity among reef sites is important in the recolonization by new corals/individuals after mass mortality, as well as in how it affects genetic mixing, diversity and relatedness. These indicators are highly tentative and require consultation with charts and knowing regional reef and current distribution patterns, and underwater observation.

Variable	***Relevance***	***Quantification***	***Data source***
Capacity for self-seeding (autochthony)	Recruitment of new corals appears to be more strongly driven by self-seeding than previously thought.	Patchiness of coral communities up to 1 km scale, robustness/diversity of adult populations for reproduction.	In situ, reference
Capacity for external seeding (allochthony) – small scale	Larval density decreases with distance from the source, thus inter-reef distances important for allochthonous larval seeding.	Connectedness of reef systems on 10 km scale, combined shapes, upstream/downstream and inter-reefal habitat considerations.	In situ, reference
Capacity for external seeding (allochthony) – large scale	Larval density decreases with distance from the source, thus distances between major reef tracts important for allochthonous larval seeding.	Distance from nearest reef system/complexity in regional reef biome, scale of 100s of km.	In situ, reference
Suitability of currents in maintaining connectivity among reefs	Locations within direct current flows will have enhanced capacity for external seeding of larvae, current systems maximizing flow among reefs and locations will maximize connectivity among sites.	From no connection (cross-flow) to strong connection (linear flows, eddies, reversing flows).	In situ, reference
Natural larval dispersal barrier	Natural dispersal barriers reduce the degree of external seeding of larvae	Distance to, size and nature of nearest natural dispersal barrier.	In situ, reference
Anthropogenic larval dispersal barrier	Anthropogenic factors that enhance natural barriers or create new barriers to external seeding of larvae	Distance to, size and nature of nearest anthropogenic dispersal barrier and/or enhancement of natural barriers.	In situ, reference

3.6.6.11. Anthropogenic factors - negative

Anthropogenic factors influence many different ecological processes on coral reefs. Of principal interest to this assessment method is how they alter the range of natural factors addressed above, in general in negative directions. Estimation of the influence of anthropogenic factors focuses on the degree to which they might shift natural factors.

Factor	***Variable***	***Relevance***	***Quantification***	***Data source***
Water quality	Nutrient input	Nutrient enhancement or eutrophication alters many reef processes, in particular enhancing algal and microbial growth, and metabolically stressing corals.	Estimate degree of effect of anthropogenically derived nutrients on site, from zero to extreme.	In situ, reference, long term
	Pollution (chemical)	Chemical pollution causes metabolic stress to reef organisms, either causing mortality, or reducing their ability to withstand other stresses	Estimate degree of effect of anthropogenic pollutants on site, from zero to extreme. Distance to pollution sources can be an alternative.	In situ, reference, long term
Substrate quality	Pollution (solid)	Solid wastes foul the substrate and may make it unsuitable for coral recruitment and growth.	Presence of solid waste on site and/or distance to sources.	In situ, reference, long term
	Turbidity/ Sedimentation	Anthropogenically enhanced turbidity and sedimentation in general negatively affects corals, though see turbidity factor.	Estimate degree of effect of anthropogenic factors on turbidity/sedimentation at site	In situ, reference, long term
	Physical damage	Physical damage to the site, or to corals results in mortality and/or inhibits recovery.	Estimate degree of effect of physical damage on site	In situ, reference, long term
Fishing	Fishing pressure	Overfishing causes reef degradation by changing trophic web structures, altering top-down ecological controls and leading to phase shifts.	Estimate degree of fishing by observation underwater and/or using catch monitoring data, local knowledge and other sources.	In situ, reference, long term
	Destructive fishing	Destructive fishing causes physical damage to the site, and/or alters the balance of fish population dynamics.	Estimate destructive fishing by observation underwater and/or using catch monitoring data, local knowledge and other sources	In situ, reference, long term

Fishing pressure, on high-value top predators By – Cheryl-Samantha Owen, Save Our Seas Foundation

3.6.6.12. Anthropogenic factors – positive (management)

Anthropogenic factors that positively influence ecological processes on coral reefs are generally implemented through explicit management frameworks. Three principal classes of management are identified here, as these act differently on the various resilience factors already listed.

Factor	***Variable***	***Relevance***	***Quantification***	***Data source***
Management	Biodiversity protection/ MPA	Protection of biodiversity from degrading anthropogenic factors using MP's and other tools focused on protecting sites from degrading influences	Presence and effectiveness of protected area-based management	In situ, reference
	Resource extraction/ fishing	Protection from extraction of resources by fishing or other activities, focused on regulations that affect extraction and offtake.	Presence and effectiveness of resource management measures limiting extraction	In situ, reference
	Environmental/ water quality	Limitation of human activities that degrade environmental quality, such as pollution	Presence and effectiveness of e.g. ICZM or municipal/waste-water management	In situ, reference

3.6.7. Materials

Wet	***Dry***
Datasheet Temperature loggers – as needed light/radiation meters – as needed	Indicator/criterion table for constant updates.

3.6.8. Background data

Background data required for this section is intensive, and the primary need for the information from section 2.7. Each resilience factor and constituent indicator, above (or from the datasheet) should be the subject of a literature/information search, and in each case develop a case history of the study site and cite references that can be sourced for more detail. The background data should then be interpreted together with the field-based indicator to obtain a final indicator level for each factor. In some cases, only the field observation can be used, in other cases where information is available (e.g. distance to 50 m contour from charts, or fishing effort and physical impacts from fisheries data), the field observation can be replaced by harder data, with the justification written out.

4. Data management and analysis

4.1. Archiving and storing data

Primary data storage is Microsoft Excel spreadsheets, as these are generally more accessible to the researchers and managers who will participate in this project. Data entry worksheets and procedures are provided for each dataset in section 3.

Each project should maintain a higher-level folder that will contain all the data and analysis files, with each dataset held in its own folders. A convention for folder and file naming is essential to maintain order, and each filename should include its methodology/data type, site and date of surveys, followed by any relevant version numbers/analyst initials to track different versions.

Parent folder	***Data folders***	***Data files***
Data-Site name	1-benthic	a-Original raw file (Excel)
	2-coralcomm	b-Clean data file (Excel)
	3-coralsiz	c-Main analysis worksheets (Excel)
	4-coralcond	d-Subsidiary analysis sheets (Excel)
	5-fish	e-Multivariate analysis files (Primer)
	6-resilindic	f-other analyses …

During data entry and once the full datasets are entered, backup copies of all files must be kept.

Participating sites will be joined in a network for analyses with the following obligations:

- Sites funded by CCCR – full dataset provided to CCCR as a completed output of the surveys, with joint analysis and publication of findings. These full datasets will then be accessible to the partners in the network that are funded by CCCR and that contribute their data. A standard right of publication period of 2 years for data from an individual site will be held by the field team for stand-alone detailed publication of that data, however regional/combined analyses will be permitted during this period.

- Independently funded sites – will be invited to join the network by contributing data, with the same rights and responsibilities of others in the network. For partners that will share only analyzed/summarized data, joint publications will be possible, but not full access to the entire datasets.

4.2. Data analysis

Analysis modules for each dataset are under constant preparation and revision and will be shared as and when necessary. Analysis currently consists of:

- Basic statistics – mean, variance, ranges, frequencies – in Microsoft Excel
- Basic analysis of variance – nonparametric and parametric – Microsoft Excel or other statistical packages as available to the sites.
- Multivariate analyses – Multi-Dimensional Scaling, cluster analyes and others – Primer, funded sites to be provided with a licensed copy (Clarke & Gorley 2006, Clarke & Warwick 2001).

4.3. Reporting and publication

Reporting will be done at three levels:

1) A technical report of findings at each project area of implementation. Model reports from past projects will be provided, but each report should be tailored to local interests and needs as well (see Rufiji-Mafia-Kilwa seascape assessment, Tanzania. Obura et al. 2008a). The reporting model should emphasize an executive summary/management guidance format in which the first pages summarize the main findings with enough technical detail to explain recommendations, but limited data presentation to ensure accessibility to a broad range of readers. Detailed results and discussions follow this section and can easily be referred to when needed.
2) A regional analysis of completed sites will be done led by the CCCR, with the first one targeted for June 2009 in conjunction with an analysis workshop for partners. This will result in a technical

report following the same model as above, and using the individual site reports as primary references.

3) Peer review publications will be developed as follows:

- For each project site, focused on the primary resilience indicators for the site and the key scientific implications of the finding (e.g. Obura et al. 2008b).
- For the global dataset, on regional variability and interactions among resilience indicators.
- Full participants in data sharing can suggest specific questions to test from the datasets to be written up as peer-review publications.

5. References

Bellwood, D, Hughes, TR, Hoey, AS 2006 - Sleeping Functional Group Drives Coral-Reef Recovery. Current Biology 16, 2434–2439

Clarke KR, Gorley, RN 2006. Primer v6: user manual/tutorial. Primer-E: Plymouth.

Clarke KR, Warwick, RM. 2001. Change in marine communities: an approach to statistical analysis and interpretation. 2nd edition. Primer-E: Plymouth.

Disease Working Group, Coral Reef Targeted Rsearch for Management Project. Coral Disease booklet.

English S, Wilkinson C, Baker V (1996) Survey Manual for Tropical Marine Resources. Australian Institute of Marine Science, Townsville

Green, AS, Bellwood, D, and Choat, H (2009.). Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience.

Grimsditch, G. D. and Salm, R. V. (2006). Coral Reef Resilience and Resistance to Bleaching. IUCN, Gland, Switzerland. 52pp.

Hoegh-Guldberg, O. (1999) Climate change, coral bleaching and the future of the world's coral reefs. Greenpeace: Sydney (Australia), 28 pp.

Kohler, K.E. & Gill, S.M. (2006) Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. Computers & Geosciences 32:1259–1269

Marshall P, Schuttenberg H (2006) A Reef Manager's Guide to Coral Bleaching. Great Barrier Reef Marine Park Authority, Townnsville, Australia.McLeod(2007

Obura, DO (2005) Resilience, coral bleaching and MPA design. *Estuarine Coastal and Shelf Science* 603, 353-372.

Obura, DO, Grimsditch, GG (2008) – Resilience-Integrating Science and Management in Coral Reefs Relevant to Climate Change. In: Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008) Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. CORDIO Status Report 2007. CORDIO (Coastal Oceans Research and Development, Indian Ocean)/Sida-SAREC. Mombasa. http//:www.cordioea.org pp.

Obura D, Mangubhai S (2003) An Initial Assessment Of Environmental And Ecological Factors And Their Contributions To Coral Bleaching Resistance And Resilience Of Reefs In The Western Indian Ocean. In: Obura D, Payet R, Tamelander J (eds.) Proceedings of the International Coral Reef Initiatve (ICRI) Regional Workshop for the Indian Ocean, 2001. ICRI/UNEP/ICRAN/CORDIO, Nairobi (pp 97-112)

Obura, D.O., Machano, H., Ndagala, J., Zavagli, M. (2008) Opposing effects of water quality on coral bleaching resistance and recovery. Proceedings of the 11th International Coral Reef Symposium, Ft. Lauderdale, Florida, 7-11 July 2008

Oliver J, Marshall P, Setiasih N, Hansen L (2004) A global protocol for assessment and monitoring of coral bleaching. ReefBase. ICRAN, Penang (Malaysia) (35)West, JM and Salm, RV. (2003) Resistance and resilience to coral bleaching: implications for coral reef conservation and management. *Conservation Biology* 17(4), 956-967.

Siebeck UE, Marshall NJ, Kluter A, Hoegh-Guldberg O (2006) Monitoring coral bleaching using a colour reference card. Coral Reefs 25:453-460

Smith JE, Shaw M, Edwards, RA, Obura, D, Pantos, O, Sala, E,. Sandin,SA, Smriga, S, Hatay, M and Rohwer, FL I. (2006) Indirect effects of algae on coral: algae-mediated, microbe-induced coral mortality. Ecology Letters 9, doi: 10.1111/j.1461-0248.2006.00937.x.

West J, Salm R (2003) Environmental determinants of resistance and resilience to coral bleaching: implications for marine protected area management. Conservation Biology 17: 956-967

Wilkinson C (2000) Status of Coral Reefs of the World: 2000. Australian Institute of Marine Science, Townsville, Australia

6. Resources

6.1. Benthic cover

• Coral Point Count software http://www.nova.edu/ocean/cpce/index.html
• Kohler, KE and Gill, SM (2006) Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers and Geosciences* 32: 1259-1269.

6.2. Coral community structure (genera)

• Veron, C. (2000) Corals of the world Version 3. Australian Institute of Marine Sciences.

6.3. Coral size class distributions (selected genera)

• Veron, C. (2000) Corals of the world Version 3. Australian Institute of Marine Sciences.

6.4. Coral condition

• CoralWatch colour cards – Siebeck, UE, Marshall, NJ, Kluter, A and Hoegh-Guldberg, O. (2006) Fine scale monitoring of coral bleaching using a reference card.
• Coral disease guide – Disease Working Group (2008) - www.gefcoral.org/
• Aeby, G. (2007) Coral diseases. NOAA and Hawai'i Institute of Marine Biology
• McLeod (2007) Coral lesions from multiple sources. TNC

6.5. Fish community structure - herbivores

• Green, A, Bellwood, D and Choat, H. (2009) Monitoring functional groups of herbivorous reef fishes as indicators of coral reef resilience. The Nature Conservancy and James Cook University.

6.6. Resistance and resilience indicators

• Resilience indicator table – pages 59 to 70 of this manual
• West, J and Salm, R. (2003) Resistance and resilience to coral bleaching: Implications for coral reef conservation and management. *Conservation Biology* 17: 956-967.
• Obura, D. (2005) Resilience and climate change: Lessons learnt from coral reefs and bleaching in the Western Indian Ocean. *Estuarine, Coastal and Shelf Science* 63: 353-372.
• Grimsditch, G and Salm, R. (2006) Coral reef resilience and resistance to bleaching. IUCN.

6.7. Data entry and analysis

• Datasheets and basic analysis sheets provided as appendices to this manual
• Primer software manual and teaching resources. Clarke KR and Gorley, RN (2006) and Clarke KR, Warwick, RM (2001)

7. Field Datasheets

7.1. Coral genera

IUCN-CCCR Resilience Assessment model datasheets – March 2009		
Coral genera		
Date:	**Site:**	**Collector:**
Notes:	**Dominance:**	**Rare species:**
Abundant:		

aca	cau	dis	gyr	les	oul	poc	sty
acr	coe	eph	hal	lob	oxy	pod	sym
alv	cos	epo	hef	mad	pac	por	tra
ana	cte	fat	hep	mer	par	psa	tub
ano	cul	fav	her	mic	pav	san	tup
asm	cyc	fun	het	mil	pec	sco	tur
ast	cyn	gal	hor	mon	phy	ser	zoo
aus	cyp	gar	hyd	mtp	pla	sid	
bar	dia	gon	lep	mya	plg	sta	
bla	dip	gop	leo	myc	pls	stc	

Date:	**Site:**	**Collector:**
Notes:	**Dominance:**	**Rare species:**
Abundant:		

aca	cau	dis	gyr	les	oul	poc	sty
acr	coe	eph	hal	lob	oxy	pod	sym
alv	cos	epo	hef	mad	pac	por	tra
ana	cte	fat	hep	mer	par	psa	tub
ano	cul	fav	her	mic	pav	san	tup
asm	cyc	fun	het	mil	pec	sco	tur
ast	cyn	gal	hor	mon	phy	ser	zoo
aus	cyp	gar	hyd	mtp	pla	sid	
bar	dia	gon	lep	mya	plg	sta	
bla	dip	gop	leo	myc	pls	stc	

7.2. Coral sizes

IUCN-CCCR Resilience Assessment model datasheets – March 2009																								
Coral size																								
Date:							**Site:**								**Collector:**									
A) Large corals	**Transect 1**												**Transect 2**											
Genus	**'11-20**				**'21-40**			**'41-80**		**80 - '160**	**'160 -320**	**>>**	**'11-20**				**'21-40**			**'41-80**		**'160**	**'320**	**>>**
Acropora																								
Pocillopora																								
Stylophora																								
Seriatopora																								
Montipora																								
Porites (mass)																								
Pavona																								
Porites(bra)																								
Galaxea																								
Echinopora																								
Platygyra																								
Favia																								
Favites																								
Goniastrea																								
Leptastrea																								
Lobophyllia																								
Fungia																								
Hydnophora																								
Coscinaraea																								
B) Small corals																								

7.3. Condition

IUCN-CCCR Resilience Assessment model datasheets – March 2009			
Coral condition			
Date:	**Site:**	**Collector::**	
C) Coral condition			
Time and associated coral size transects		**Coral Size**	
Genus/species and size class		**Classes (cm)**	
BLEACHING (BASIC):	B2 - Bleached ;	C1	1-2.5
0 - No bleaching evident;	B3 - Bleached + partly dead ;	C2	3-5
B1 - Partially bleached (surface/tips) or pale but not white;	D - Recently dead	C3	6-10
DISEASES:	LESIONS/OTHER	C4	11-20
TUM-Growth anomalies/tumours	Drupella	C5	21-40
SEB-Skeletal eroding band/skeletal eroding disease – powdery/eroded skeleton	COTS	C6	41-80
BBD-Black Band Disease (BBD)	Competition	C7	81-160
BrD - Brown/other colour bands,	Bioeroders	C8	161-320
WBD - White Band Disease	Feeding scars	C9	> 320
WP - White Plagues/Syndromes	Human damage (var)		
WS - Spots –white spots (*Porites*),	Dynamite crater		
PS - pink/purple spots/lines (*Porites*),			
BP - Blotch/spot disease – large dark spots/patches			

7.4. Fish-herbivore functional groups

IUCN-CCCR Resilience Assessment model datasheets – March 2009		
Fish-herbivore functional groups		
Date:	**Site:**	**Collector::**

LONG SWIM - Herbivores	Groupers:
Bolbometopon sp.	
Chlororus sp.	
Scarus sp.	
Cheilinus undulatus	Emperors/Snappers
Sharks	

Point Counts			**1**	**2**	**3**	**4**	**5**	**6**
Scarids	Bolbometopon	Excavators						
	Chlorurus	Excavators						
	Cetoscarus	Excavators						
	Scarus	Scrapers						
	Hipposcarus	Scrapers						
	Calotomus	Browsers						
	Leptoscarus	Browsers						
Acanthurids	Ringtail: blochii, dussumieri , leucocheilus, xanthopterus, nigricauda, olivaceus	Grazer						
	Acanthurus (excl. ringtails)	Graz/Detr						
	Zebrasoma	Grazer						
	Naso - brachycentron, lituratus, unicornis	Graz/Brows						
	Naso - annulatus, brevirostris, vlamingii	Graz/Brows						
	Naso - Other species	Planktivores						
	Ctenochaetus	Detritivores						
Others	Siganids	Graz/Brows						
	Centropyge	Grazer						
	Chub/Kyphosus	Browsers						
	Batfish	Browsers						

7.5. Fish-basic functional groups

IUCN-CCCR Resilience Assessment model datasheets – March 2009										
Fish-basic functional groups										
Date:		**Site:**			**Transect:**			**Collector::**		
		3-10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**	**70-80**	**>>80**
Carangidae	Piscivores/ scavengers									
Haemulidae	Piscivores/ scavengers									
Lethrinidae	Piscivores/ scavengers									
Lutjanidae	Piscivores/ scavengers									
Mullidae	Piscivores/ scavengers									
Serranidae	Piscivores/ scavengers									
Labridae	Invertivores									
Chaetodontidae	Coral obligat/ indicators									
Siganidae	Herbivore									
Kyphosidae	Browsers									
Ephippidae	Browsers									
Pomacentridae	in water column									
	on benthos									
Balistidae	Invertivores									
	planktivores									
Pomacanthidae	Invertivore									
Centropyge	Herbivore									
Scaridae	Excavators - Bumpheads									
	Scrapers - Scarus									
	Browsers - Calotomus, Leptoscarus									
Acanthuridae	Unicorn									
	Acanthurus, Zebrasoma									
	Others- Detritivore, Ctenochaetus									
	Planktivore/water column									

7.6. *Resistance/resilience factors*

IUCN-CCCR Resilience Assessment model datasheets – March 2009

Resistance/resilience factors

Date:	Site:	Collector

	Factor	Variable				Comments
1. Benthic	Coral	Hard Coral				
		Soft Coral				
	Algae	Fleshy Algae				
		Turf Algae				
		CCA				
	Substrate	Rubble				
2. Physical	Substrate & Morphology	Top.Compl. - micro				
		Top. Compl. - macro				
		Sediment texture				
		Sediment layer				
	Cooling &flushing	Temperature				
		Currents				
		Wave energy/ exposure				
		Deep water (30-50m)				
		Depth of reef base				
	Shade & screen	Depth				
		Visibility (m)				
		Compass direction/ aspect				
		Slope (degrees)				
		Physical shading				
		Canopy corals				
	Extremes & Acclimatization	Exposed low tide				
		Ponding/ pooling				
		Temperature variability				
		Survival of past bleach				
8. 8Anthropogic	Water	Nutrient input				
		Pollution (chemical)				
	Substrate	Pollution (solid)				
		Turbidity/ Sedimentation				
		Physical damage				
	Fishing	Fishing pressure				
		Destructive fishing				
	Connectivity	Dispersal barrier				
	Management	MPA/biodiv				
		MPA/biodiv				
		Environment/ ICZM				

Site	Description, sketch, etc.

	Factor				Comments
3-Coral Condition	Bleaching				
	Mortality-recent				
	Coral disease				
	Mortality-old				
	Recovery-old				
4-Coral Population	Recruitment				
	Fragmentation				
	Dominant size class				
	Largest corals (3)				
5-Coral associates	Obligate feeders				
	Branching residents				
	Competitors				
	Bioeroders (external)				
	Bioeroders (internal)				
	Corallivores (negative)				
6-Fish groups	Herbivores				
	Excavators				
	Scrapers				
	Grazers/ Browzers				
	Piscivores				
7-Connectivity	Self-seeding				
	Local seeding (10 km)				
	Distant seeding (100)				
	Currents				
	Dispersal barrier				

8. Resilience Indicators Table

The table in the following pages specifies levels for recording each indicator. This should be used as a basis for each new area, but the table needs to be edited and adjusted for each area but staying consistent with the approach indicated.

For best results, contact the CCCR to check on adjustments made to the table. The original table can be downloaded in Microsoft Excel format at the CCCR website, and used as a template for further adjustments. http//:cms.iunc.org/cccr

IUCN-CCCR Resilience Assessment of Coral Reefs

Resistance/Resilience indicators reference table. For use in Section 3.6

Editors: David Obura & Gabriel Grimsditch — Table based on initial work and consultations with Paul Marshall, Naneng Setiasih

	Factor	Variable		Quantity	Resilience Index Very low 1	 Low 2	 Moderate 3	 High 4	 Very high 5	Notes	Direct
1. Benthic	Coral	Hard Coral	1	% cover	Estimate % cover in the reef area at a gross level (e.g. 10% levels, or 1/3, 1/2, etc). Then convert based on minimum, maximum and distribution of values recorded at site						+
		Soft Coral	2								+
	Algae	Fleshy Algae	3								-
		Turf Algae	4								-
		CCA	5								+
	Substrate	Rubber/ substrate stability	6								-
2. Physical	Substrate & Morphology	Top. Compl. - micro	7	Complexity on recruitment scale - mm to 10 cm spaces	Smooth surfaces	Rough textured surface, to 1 cm texture. Pavement w some topo.	Moderate micro-scale structure/crevices	Diverse 3D spaces between corals/ boulders/etc, to 10 cm	Deep intricate branching/interlocking framework, to 10 cm		+
		Top. Compl. - macro	8	Complexity on large body scale - to 3-5 m spaces	Flat	Corals/ relief, 1-10 cm texture	Corals/crevices about 0.5-1 m relief, separated by > 5 m	Corals/relief 1-2 m, some development of structure - bommies, etc 3-6 m apart	Major spur/ groove/ heads > 2 m relief; pillars/ caves and major structures a diver can pass through/between		+

IUCN-CCCR Resilience Assessment of Coral Reefs

Resistance/Resilience indicators reference table. For use in Section 3.6

Editors: David Obura & Gabriel Grimsditch — Table based on initial work and consultations with Paul Marshall, Naneng Setiasih

	Factor	Variable		Quantity	Resilience Index Very low 1	Low 2	Moderate 3	High 4	Very high 5	Notes	Direct
2. Physical (continued)	Substrate & Morphology (cont.)	**Sediment texture**	9	Texture and nature of sediment, from fine terrestrial to coarse carbonate	None	Coarse grains/ carbonate	Coarse to fine sand	Fine sand, mixed origin	Fine silt/high organic or terrestrial content.	High sediment influence causes stress in corals	-
		Sediment layer	10	Depth of sediments on rocky substrates	None	Very fine/interspersed	Few millimetres in patches < 20% cover	Embedded in algal filaments, thin	Several millimetres, embedded in algal filaments, invading coral edges.	High sediment influence causes stress in corals	-
	Cooling & flushing	**Temperature (C)**	11	Temperature reading during dive	Temperature reading during dive, convert based on minimum, maximum and distribution of values recorded at site					High temperature is bad, causes stress	-
		Currents	12	Local exposure of site to moving water	None/very low	Low/general background conditions, nothing	Linear reef edges and structures exposed to general water flow up	Reef edges/points and more complex features in flow conditions	Tidal channels, pinnacles/ patches in high flow areas, major	Convert to numerical through tests	+
		Wave energy/ exposure	13	Wave energy and exposure to wave-generating weather	Zero - all non-wave zone sites, fully sheltered	Indirect/dissipated exposure to wind/ swell (e.g. behind primary barrier)	Evidence for wave influence, but not extreme, presence of some fine-bra corals. not direct face onto wind/swell, but locally rough	Angled face on to wind/swell	Maximum local - clear evidence of robust wave zone structures, direct face on primary wind/swell direction	List out all reef zones and which of the categories they would fall into	+
		Deep water (30-50m)	14	Proximity to 30-50 m on reef front, km	Distance in m or km, obtained from local knowledge or charts where possible						-

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch					Table based on initial work and consultations with Paul Marshall, Naneng Setiasih						
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
		Depth of reef base	15	Depth of reef base if present	Estimate or measured depth						**+**
2. Physical (continued)	**Shade & screen**	**Depth**	16	Average depth in meters	Average depth of study site						**+**
		Visibility (m)	17	Estimate visibility in meters	Assign based on local area distribution of values from minimum to maximum					High visibility is bas as less absorption of light	**-**
		Compass direction/ aspect	18	Facing direction to sun at summer noon	Strongly towards		Neutral		Strongly away		**+**
		Slope (degrees)	19	Slope angle, estimate in degrees	Assign based on local area distribution of values from minimum to maximum					Convert to numerical based on distribution	**+**
		Physical shading	20	Subjective shading by topographical features	None	Some shading from vertical/thin structures e.g. columns	Moderately developed columnar forms and/or some vertical faces on bommies	Large vertical faces in multiple directions/ complex faces causing variable shading	Overhangs/above-water shading		**+**
		Canopy corals	21	Degree of multi-storey canopy in coral community	None	Minor - shading by some erect corals	Moderate coral community at multiple levels	Over-branching of canopy corals	Extensive over-branching of canopy corals		**+**

IUCN-CCCR Resilience Assessment of Coral Reefs

Resistance/Resilience indicators reference table. For use in Section 3.6

Editors: David Obura & Gabriel Grimsditch | Table based on initial work and consultations with Paul Marshall, Naneng Setiasih

	Factor	**Variable**		**Quantity**	**Resilience Index** **Very low** **1**	**Low** **2**	**Moderate** **3**	**High** **4**	**Very high** **5**	**Notes**	**Direct**
2. Physical (continued)	**Extremes & Acclimatization**	**Temperature variability**	22	In situ, degrees variation in temperature, interpret with local knowledge	Temperature variability at site depth during dive, convert based on minimum, maximum and distribution of values					Variability promotes acclimatization over time, but perhaps only up to a point	+
		Exposed low tide	23	Aerial exposure of corals during spring low tides - effect of shallows	None	One or two isolate heads	Yes, small portion/area of community	Yes,	Yes, significant portion of community	Variability promotes acclimatization over time, but perhaps only up to a point	+
		Ponding/ pooling	24	Degree of isolation/ ponding of shallow water during low tide, exposure to water that has heated at low tide - effect of enclosure/transport	None. Open reef front with unrestricted water motion.	Very infrequent. Large bay/semi-enclosed systems with somewhat limited circulation.	Occasional occurrence, during spring low tides. Small bays with limited circulation. Locations vulnerable to overflow of ponded waters (e.g. reef edges off large shallow banks.	Intricate/reticulate reef systems impeding circulation	Frequent occurrence during all low tides, complete isolation of small bodies of water for some hours.		+
		Survival of past bleaching events	25	Evidence of corals having survived recent bleaching events, particularly with respect to differential survival	None, mortality near complete				High, near-total survival of past bleaching events	Survival indicates acclimatization	+

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch					Table based on initial work and consultations with Paul Marshall, Naneng Setiasih						
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
3. Coral Condition	**Current**	**Bleaching**	26	Amount of current bleaching	None	Minor background/ normal bleaching	Low level bleaching and paling at up to 20% of population	Moderate to high levels of bleaching up to 40% of population, or to 80% paling	Greater than 50% bleaching	Verify with coral condition measurements	-
		Mortality-recent	27	Amount of current mortality from any cause	None	Minor background/ normal bleaching, < 10 %	Moderate levels of mortality, < 25%	High levels of mortality, about 50%	Very high levels of mortality, > 75%	Verify with coral condition measurements	-
		Coral disease	28	Disease prevalence at site	None	< 5 incidence at site; 1 per 25*1 m transect	10-15 diseased corals seen; 2-4 per 25*1 m transect	> 30 corals seen with disease, or > 10% population, > 20 per 25*1 m transect	Predominance of disease with large proportions of colony area affected	By observation	-
	Historic	**Mortality-old**	29	Amount of old mortality visible	None	<10%, may not be evident if good recovery	Old mortality evident at < 20-40 %	Old mortality around 50-70%	High old mortality at >75%	By observation, combining with historical data if possible	-
		Recovery-old	30	Degree of recovery from old mortality	No recovery at all, full extent of mortality is visible	Some recovery, adding back 10(25)% of pre-existing community	30(50)% recovery	50-75(75)% recovery. Old mortality visible by dead skeletons, partial mortality, new growth, etc.	Near-full recovery, old mortality only visible by inference from new corals/cover	By observation, combining with historical data if possible	+

<table>
<tr><td colspan="12">IUCN-CCCR Resilience Assessment of Coral Reefs</td></tr>
<tr><td colspan="12">Resistance/Resilience indicators reference table. For use in Section 3.6</td></tr>
<tr><td colspan="6">Editors: David Obura & Gabriel Grimsditch</td><td colspan="6">Table based on initial work and consultations with Paul Marshall, Naneng Setiasih</td></tr>
<tr><td rowspan="3"></td><td rowspan="3">Factor</td><td rowspan="3">Variable</td><td rowspan="3"></td><td rowspan="3">Quantity</td><td colspan="5">Resilience Index</td><td rowspan="3">Notes</td><td rowspan="3">Direct</td></tr>
<tr><td>Very low</td><td>Low</td><td>Moderate</td><td>High</td><td>Very high</td></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td rowspan="4">4. Coral Population</td><td rowspan="4">Population Biology</td><td>Recruitment</td><td>31</td><td>Amount of sexual recruitment</td><td>None</td><td>Low - < 1 per m2</td><td>Moderate 2-4 per m2</td><td>High, 5-10 per m2</td><td>Very high > 15 per m2</td><td>Amount of sexual recruitment</td><td>+</td></tr>
<tr><td>Fragmenta-tion</td><td>32</td><td>Amount of asexual recruitment/ reproduction</td><td>None</td><td>Low - < 1 per m2</td><td>Moderate 2-4 per m2</td><td>High, 5-10 per m2</td><td>Very high > 15 per m2</td><td>Amount of asexual recruitment/ reproduction</td><td>+</td></tr>
<tr><td>Dominant size class</td><td>33</td><td>Overall size class structure of site</td><td>All corals small, < 20 cm</td><td>Mostly small/medium corals, no large ones, few moderate-large ones.</td><td>Mid-size classes abundant, but very few large ones. Over-dominance of few sizes</td><td>Many large corals, or intermediate-large</td><td>Full range of size classes, with many in mid-sizes and diverse large corals.</td><td>Overall size class structure of site</td><td>+</td></tr>
<tr><td>Largest corals (3)</td><td>34</td><td>Size in meters, and ID of corals</td><td colspan="6">The average of the largest three corals, converted into size classes used in the coral size class distribution section, and labelled into 1-5 (5= > 3.2m, 4= 1.6-3.2 m, etc)</td><td>+</td></tr>
<tr><td rowspan="2">5. Coral Associates</td><td rowspan="2">Positive</td><td>Obligate feeders</td><td>35</td><td>Abundance and diversity of obligate coral feeders</td><td>None</td><td>Few, < 5 seen at site</td><td>6-20</td><td>25-50</td><td>> 50</td><td>Do by species/ group</td><td>+</td></tr>
<tr><td>Branching residents</td><td>36</td><td>Abundance and diversity of fish/ crustaceans residents in corals</td><td>None</td><td>A few seen</td><td>Some individuals/ some corals commonly seen</td><td>Large number of hosts and residents apparent</td><td>Large numbers/ highly prominent feature of community</td><td>Focus on Acropora and Pocillopora colonies</td><td>+</td></tr>
</table>

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch						Table based on initial work and consultations with Paul Marshall, Naneng Setiasih					
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
5. Coral Associates (continued)	**Negative**	**Competitors**	37	Abundance/ prevalence of competitive interactions between corals and others	None	Low - potential competitors present but interactions not prominent	Competitors present and interactions commonly seen, only slightly detrimental to corals	Clear competition for space, with evidence of negative impacts on corals.	Competitors abundant, clear negative impacts on corals from competitors.	Abundance/ prevalence of competitive interactions between corals and others	-
		Bioeroders (external)	38	Abundance/prevalence of bioeroders - scrapers (urchins, other nonfish)	none	Bioeroders present but low numbers and interactions not prominent	Bioeroders common and interactions/ impacts seen, only slightly detrimental to corals/benthos. ≈ 1 m^{-2}	Clear bioerosion happening, moderate negative impacts on corals/benthos. ≈ 5 m^{-2}	Bioeroders abundant, clear negative impacts on corals/benthos. > 10 m^{-2}	Abundance/prevalence of bioeroders - scrapers (urchins, other nonfish)	-
		Bioeroders (internal)	39	Abundance/prevalence of bioeroders	none	Bioeroders present but low numbers and interactions not prominent	Bioeroders common and interactions/ impacts seen, only slightly detrimental to corals/benthos.	Clear bioerosion happening, moderate negative impacts on corals/benthos.	Bioeroders abundant, clear negative impacts on corals/benthos.	Abundance/prevalence of bioeroders	-
		Corallivores (negative)	40	Abundance/prevalence of corallivores	none	Corallivores present but low numbers and interactions not prominent. No or v minor predation seen.	Corallivores common and interactions/ impacts seen, only slightly detrimental to corals (up to 5 dead corals?).	Clear predation happening, moderate negative impacts on corals (10-30 dead corals.	Corallivores abundant, clear negative impacts on corals (50+ dead corals)	Abundance/prevalence of corallivores	-

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch						Table based on initial work and consultations with Paul Marshall, Naneng Setiasih					
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
6. Fish groups	**Herbivores**	**Herbivores**	41	Visual assessment of abundance/diversity of herbivores	Very few species/very low numbers/high algal cover. No eroders/ scrapers	Lack of eroders/ scrapers, reasonable schools of small herbivores. Algal turf/ fleshy algae abundant	Diversity of/within guilds moderate/ depleted, algal turf abundance	High diversity/ abundance of fish herbivores, algal cover moderate, v low CCA	High diversity/ abundance of fish herbivores, v. thin algal cover/high CCA	Visual assessment of abundance/diversity of herbivores	**+**
		Excavators	42	Eroding grazers - Bolbometopon, others, gouging bottom	None	1-3	5-10	20	30+	However high excavator populations cause extensive damage!!	**+**
		Scrapers	43	Smaller parrotfish, scraping bottom	0-2	5-10	20-30	40-80	100+		**+**
		Grazers/ Browzers	44	Some parrotfish, surgeonfish - cropping algae	0-2	5-10	20-30	40-80	100+		**+**
	Top predators	**Piscivores**	45	Top predators, particularly of fish	None	3-10 individuals, mostly small to medium sizes	Medium size individuals, moderate schools or presence in ones/twos.	2-3 large individuals, large numbers of medium sizes	Large individuals, > 10 seen, large schools		**+**

IUCN-CCCR Resilience Assessment of Coral Reefs

Resistance/Resilience indicators reference table. For use in Section 3.6

Editors: David Obura & Gabriel Grimsditch — Table based on initial work and consultations with Paul Marshall, Naneng Setiasih

	Factor	Variable		Quantity	Resilience Index Very low 1	 Low 2	 Moderate 3	 High 4	 Very high 5	Notes	Direct
7. Connectivity	**Dispersal**	**Self-seeding**	46	Connectivity at local scale of 1 km reefs	Very low. Reef sizes on scale of 10s meters, separated by > 1 km of poor habitat.	Reef patches on 100s m scale, separated by larger distances of poor habitat	Patchwork of coral communities on 100s m scale with smaller inter-reef distances.	Continuous coral communities in liner reef system of several km	Continuous coral communities over 2D area of several kilometres	How to build in diversity/ complexity/ health of reef communities	+
		Local seeding (10 km)	47	Connectivity at between-reef scale of about 10 km	Very low, nearest reef structures > 10 km distances	Reef structures on 1 km scale, but widely separate up to 10 km	Local patchwork of reefs on 1-5 km scale with similar distances between.	Continuous coral communities in linear system to 20-50 km	Continuous coral communities over 2D area of several tens kilometres	How to build in diversity/complexity/ health of reef communities	+
		Distant seeding (100 km)	48	Connectivity at regional scale > 100 km	Very low, nearest reef system > 100 km away	Isolated reef areas, some 20-80 km apart.	Patchwork of local reefs systems dispersed over area 100s of km in extent. Separated by poor habitat on 10-20 on scale	Large reef systems over 100-200 km extent occupy 50-80% of space	Extensive reef province 100s of km in extent in multiple directions.	How to build in diversity/complexity/ health of reef communities	+
	Transport	**Currents**	49	Current flow orientation and dynamics relative to coastline/reefs	Low. Current directions near-perpendicular to reef systems; very low flow.		Moderate, currents medium speed/ variability, moderately oriented with reef systems.	Currents strongly oriented with reef systems, linear/bi-directional flow	Complex eddies and circulating currents	Current flow orientation and dynamics relative to coastline/reefs	+
		Dispersal barrier	50	Presence and scale of dispersal barriers	None				Very high, > 200 km open water and/or poor environmental. Quality	Presence and scale of dispersal barriers	+

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch						Table based on initial work and consultations with Paul Marshall, Naneng Setiasih					
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
8. Anthropogenic	**Water**	**Nutrient input**	51	Extent of anthropogenic addition of nutrients on site	None	Some evidence of greater algal growth and/or epiphytes, but no impact on coral communities	Visible impact, some indicators present, but no phase shift	Increasing levels of mortality/ enhancement of algae/ microbial communities and silt.	Very high, clear evidence of eutrophica-tion, incipient phase shift, disease, coral mortality, algal/microbial/ silt enrichment	Extent of anthropogenic addition of nutrients on site	-
		Pollution (chemical)	52	Extent of anthropogenic pollutants on site	None		Some evidence, and some evidence of impact to corals/reef		Very high/visible	May be done/replaced by distance proxy	-
	Substrate	**Pollution (solid)**	53	None	Occasional pieces of solid waste/trash, no clear impact on coral community	Some trash, clear smothering/impact on corals abut low level of mortality		Abundant trash/solid waste wrapped in corals, algae, etc. Clear mortality as a result.		None	-
		Turbidity/ Sedimentation	54	None	Some influence on sedimentation likely, but minor effect above natural levels.	Natural high sediment regime, somewhat increased by anthropogenic activities.	Sediment regime strongly altered/worsened by anthropogenic activities.	Near-total. Almost all high-turbidity/sediment due to anthropogenic sources.		None	-
		Physical damage	55	None	Some physical damage, no impact on overall mortality of corals.	Some physical damage clear with some impact on mortality but at low levels compared to natural	Physical damage clearly important part of overall mortality, but only minor decline in coral cover.	Very high, clear evidence of disturbance and high mortality.		None	-

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch					Table based on initial work and consultations with Paul Marshall, Naneng Setiasih						
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
8. Anthropogenic (continued)	**Fishing**	**Fishing pressure**	56	None	Low pressure, carnivores target species, but low impact in water.	Moderate pressure, but sustainable catch. Good fish populations in water, few large individuals	Populations depleted, no large individuals U/W or in catch, catch mainly of small-medium individuals.	Very high depletion of fish carnivores/ piscivores. Above-MSY catches/small sizes	Verify with fish monitoring data	None	-
		Destructive fishing	57	None	Some use, but at too-low levels to show any clear impacts	Frequent use of destructive gear, some evidence of coral mortality/damage to substrate, but low compared to natural level.	Frequent use of destructive gear and clear evidence of moderate mortality of corals/damage to substrate.	High-very extensive use of destructive gears, with clear impact on coral mortality and substrate	Verify with fish monitoring data	None	-
	Connectivity	**Dispersal barrier**	58	None	Low	Moderate	High	Very high influence, e.g. through construction, water quality alterations, etc.		None	-

IUCN-CCCR Resilience Assessment of Coral Reefs											
Resistance/Resilience indicators reference table. For use in Section 3.6											
Editors: David Obura & Gabriel Grimsditch					Table based on initial work and consultations with Paul Marshall, Naneng Setiasih						
	Factor	**Variable**		**Quantity**	**Resilience Index**					**Notes**	**Direct**
					Very low	**Low**	**Moderate**	**High**	**Very high**		
					1	**2**	**3**	**4**	**5**		
9. Management	**Management**	**Biodiversity**	59	Degree of management with biodiversity objectives	None	Some action/presence, low level of intervention, some raised awareness	Moderately effective, interventions limit disturbance but impacts visible	Effective, reasonable levels of compliance, high awareness, no risk of species/genetic loss	Very high, fully effective, no loss of species/ genetic diversity		+
		Resources	60	Degree of management with resource use limitation/ control objectives	None	Some action/presence, low level of intervention, some raised awareness	Moderately effective, interventions limit disturbance but impacts visible	Effective, reasonable levels of compliance, high awareness, resource populations moderately impacted	Very high, fully effective, full control of resource extraction protecting stock integrity and population dynamics		+
		Environmental Quality	61	Degree of management with environmental quality objectives, e.g. pollution, ICZM	None	Some action/presence, low level of intervention, some raised awareness	Moderately effective, interventions limit disturbance but impacts visible	Effective, reasonable levels of compliance, high awareness, environmental quality only slightly compromised	Very high, fully effective control of pollution and other disturbances to water and substrate quality		+

INTERNATIONAL UNION FOR CONSERVATION OF NATURE

WORLD HEADQUATERS
Global Marine Programme
Rue Mauverney 28
1196 Gland, Switzerland
marine@iucn.org

www.iucn.org/marine