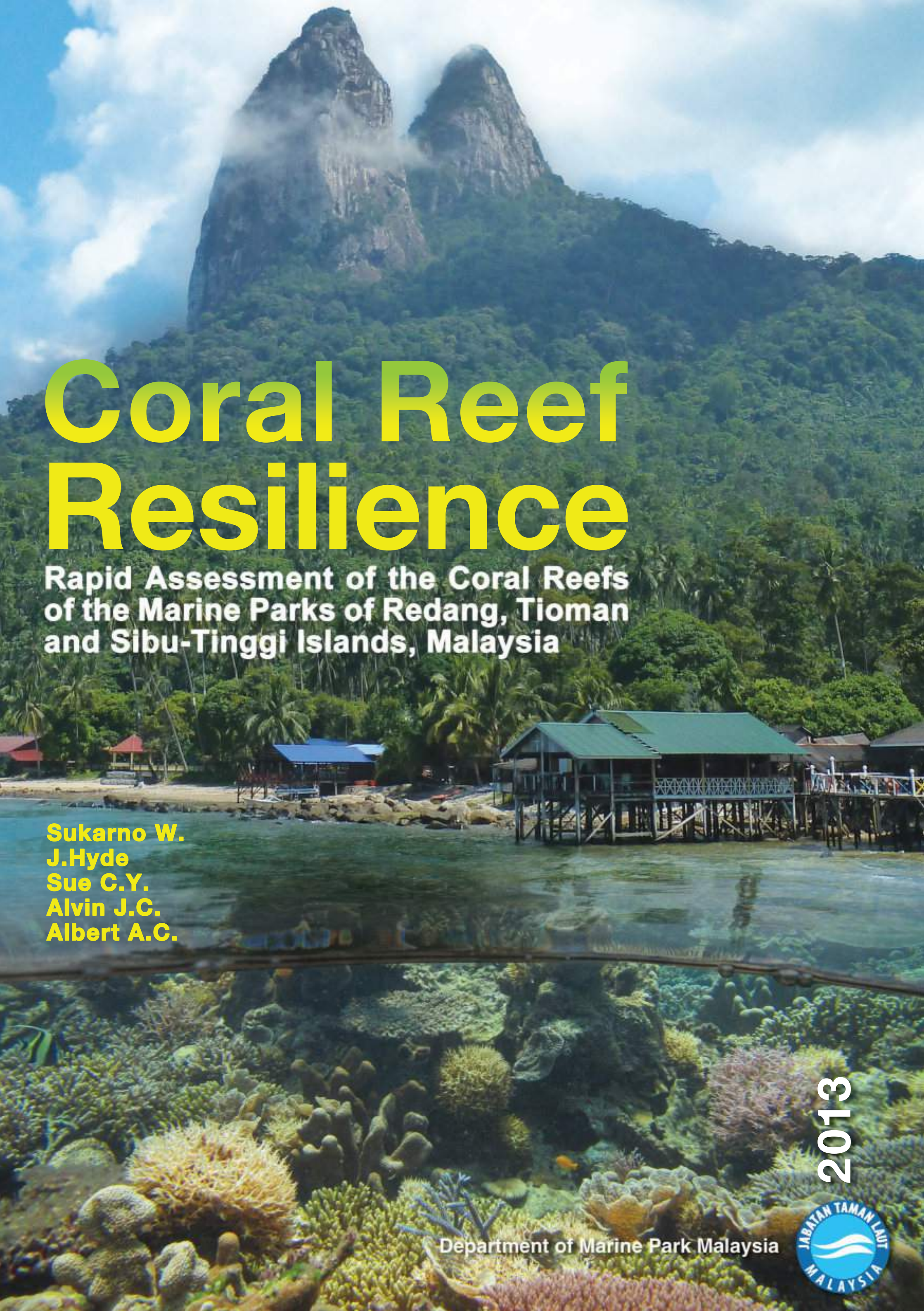

Coral Reef Resilience

Rapid Assessment of the Coral Reefs of the Marine Parks of Redang, Tioman and Sibu-Tinggi Islands, Malaysia

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Foreword

With the consent of Allah S.W.T.,

There is an urgent need to address the threat of coral deterioration due to climate change and anthropogenic causes. In 2010 alone, Malaysia experienced a mass coral bleaching event that involved almost all the coral reefs in Peninsular Malaysia. At its height in July 2010, some 80% of coral reefs were affected. The mass coral bleaching was due to sea water temperature rise that lasted several weeks and coincided with the El Nino phenomenon.

The following year, early forecasts seemed to indicate the emergence of another El Nino event and increased sea surface temperatures. These raised some concerns because most coral reefs had only just recovered from the 2010 bleaching and were still in a weakened state. Another mass coral bleaching while the coral reefs were still recovering could have been a total catastrophe, with widespread mortality of coral reefs in Malaysian waters.

Mitigation measures need to be found to address this threat, immediate actions such as coral propagation programmes, zoning and identification of resilient coral reef areas to act as core sites for "natural seeding" to nearby affected areas, will help tremendously, especially during the recovery stages. In realising this threat, a smart partnership has been formed between three organisations - Department of Marine Park Malaysia (government agency), GoM - United Nations Development Programmed/ Global Environment Facility (international agency) and Reef Check Malaysia (local NGO) - to produce this valuable book to shed some light on the sensitivity and resilience of our coral reefs in three marine park clusters located on the east coast of Peninsular Malaysia. This timely publication will contribute to identifying our most resilient coral reef areas and protecting them from the threat of climate change.

Dr. Sukarno bin Wagiman
Director General
Department of Marine Park Malaysia
Ministry of Natural Resources and Environment

November 2013

Preface

Coral reefs are a valuable ecosystem worth, according to one estimate, RM 50 billion per year in Malaysia. Ecologically they are an essential habitat and breeding ground for marine life; economically they are a source of food and jobs for millions of people. But human activities are damaging coral reefs worldwide, with impacts both local and global in scale. While local managers can reduce local impacts such as sewage pollution and tourism activities, there is little they can do about the emerging global threats, principally climate change leading to global warming. A powerful tool in conserving reefs for future generations is to identify and protect resilient reef areas – those that are most likely to withstand or quickly bounce back from the global impacts that are beyond the control of local managers. Protecting such areas provides a base from which damaged areas can recover.

This booklet describes a programme of work to conduct rapid resilience assessments of coral reefs around four islands off the East coast of Peninsular Malaysia, which we hope will form the basis for incorporating resilience concepts into management planning for Malaysia's Marine Parks. We are grateful to Dr Sukarno, Director General of the Department of Marine Park Malaysia, for his strong support of this project, which could not have been completed without funding and support from Mr. Ab. Rahim Gor Yaman from the GEF-UNDP's Marine Park Project as well as Mrs. Norizan Mazlan and Albert Apollo Chan for support throughout the project.

Julian Hyde
Reef Check Malaysia
Jun 2013

Introduction

Coral reefs are the most diverse marine ecosystems on earth. They are an important ecological and economic resource in many countries around the world, providing a range of valuable ecosystem services to millions of people. Coral reefs provide jobs, food and coastal protection, among other benefits, to over 100 million people in South East Asia.

Despite being recognised for their economic and aesthetic value, coral reefs are being damaged by a variety of both local and global threats:

- The 2008 "Status of Coral Reefs of the World" report stated that the world has effectively lost 19% of the original area of coral reefs and that 15% are seriously threatened with loss within the next 10-20 years, with a further 20% under threat of loss in the next 20-40 years.

- In 2011, "Reefs at Risk Revisited" stated that more than 60% of the world's reefs are under immediate and direct threat from one or more local sources.

These threats arise largely as a result of human activities and land use changes along coastlines adjacent to coral reefs. Local threats to coral reefs are many, and are reasonably well understood. They include:

- Over-fishing
- Destructive fishing
- Coastal development
- Pollution
- Siltation/sedimentation
- Physical impacts from tourism, including divers, snorkelers and boats.

In Malaysia, the Department of Marine Parks (National), Sabah Parks and Sarawak Forestry are tasked with managing these local threats to their protected reef areas.

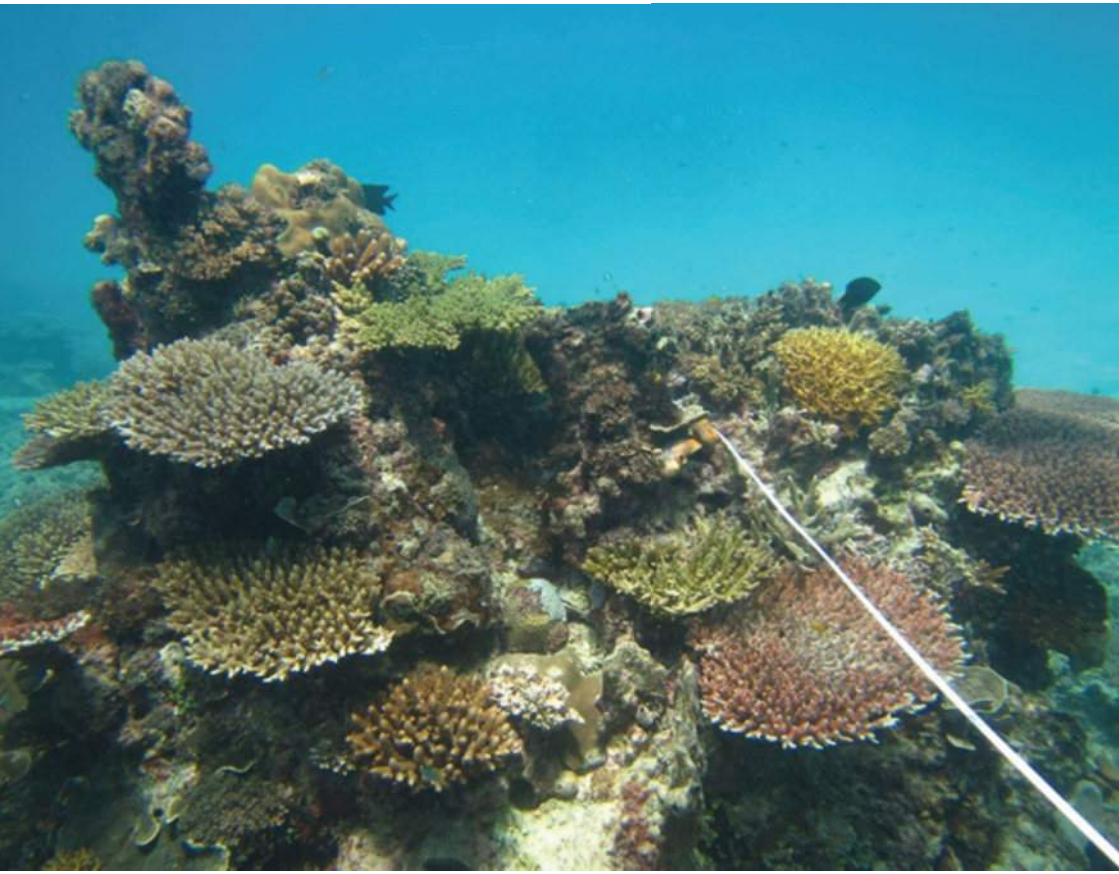
However, against these local threats, mass coral reef bleaching has emerged over recent years as a global threat that is difficult to manage locally and which can have potentially devastating effects. The first significant mass coral reef bleaching event reported in Malaysia was in 1998, as a result of which an estimated 40% of corals in reefs around Peninsular Malaysia died. Reefs had barely recovered before the 2010 mass coral reef bleaching event occurred, which fortunately saw lower coral death rates.

Scientists agree that mass coral reef bleaching is likely to occur with increasing frequency in the coming decades, and there is an urgent need to put in place plans to:

- Respond effectively to mass coral reef bleaching events with management interventions to protect reefs during bleaching events
- Build the “survivability” of coral reefs to better withstand future bleaching events.

The need for assessing the resilience of Malaysian reefs, and the application of resilience criteria in assessing the effectiveness of MPAs as well as conservation management measures, is becoming increasingly critical as Malaysian reefs are under threat from a variety of human activities. These local threats act to reduce the resilience of the reef system, undermining its ability to cope with additional stresses such as those associated with climate change, and lowering the threshold for the shift from coral-dominated phase to other phases.

Different coral reefs react differently to a given threat because of various factors that influence their resilience to disturbances. Because of their varying biological compositions and widely differing physical conditions, we can expect different coral reefs, even on the same island, to follow different routes with increasing human and natural threats. It is therefore important to develop monitoring and assessment protocols to build an understanding of reef resilience criteria for application in each management zone, and to determine how Marine Protected Area management actions can influence reef resilience.



The Coral Reef Islands

Tioman Marine Park

The Tioman Marine Park archipelago consists of nine islands with the Tioman island as the largest of the forty two (42) marine park islands of Malaysia. Located at 104^{o} 11’ E longitude and 02^{o} 47’ N latitude, the island is 19 km in length and 11 km wide and has 25,115 hectares of sea area. The topography of Tioman is unique with many beautiful features like the twin mountain peaks of Nenek Semukut a mesmerising geological feature for any sailors from ashore. The highest point is Mount Kajang at 1,030 metres high from sea level, nestles deep at the heart of the island. Most of the island eastern shores are rugged with rocky outcrop inaccessible to boat landings.

Most villages are located on the western side of Tioman, sheltered from the north easterly wind of the monsoon that blows from November until March. This coincides with the coral reef spatial distribution on the western side of the island too. Most of the coral reefs are fringing reefs type that encircles the island. With its high biological diversity, Tioman is believed as the “seed-source” for most of the marine biodiversity of the eastern part of peninsula Malaysia.

Redang Marine Park

Redang island is one of the two marine park centres in the state of Terengganu with its water covered an area of 12,750 hectares. The Redang Marine Park consists of a cluster of nine islands and located strategically at 103^{o} 01' E longitude and 05^{o} 47' N latitude or 22 kilometres from the mainland of north eastern part of Peninsular Malaysia. Redang is popular with its famously white sandy beaches and blue azure sea. The Marine Park Centre is located on the adjacent smaller Pinang island, where a marine turtle hatchery is in operational with a yearly hatchlings release of twenty thousand. The species richness is not only confined to the underwater domain, but can be found on land as well. One's only needs to quietly observe the unique reptiles, insects, birds and the occasional troop of monkeys on the prowl for leftover food from the tourists. After dusk during a fine weather, a female green turtle will drag herself out to nest on the white sandy beach. A renowned marine ecologist Professor Dr. Ridzuan Abdul Rahman (comm.) had once noted that Redang in the 1970's was a glittering jewel of marine paradise. According to him, the table coral Acropora that stretches over two metres across is a common sight. Even though table coral can still be found around Redang water, the sighting of large table coral is less common nowadays. The external environment stresses over the following decades, has caused the lustre of Redang to become a little bit dimmer.

Sibu-Tinggi Marine Park

Yet less studied as compare to the two former marine parks, Sibu-Tinggi Marine Park archipelago is a cluster of 10 islands and have a combine sea coverage of 14,440 hectares. Located at 104^{o} 07' E longitude and 02^{o} 14' N latitude or south eastern of Peninsular Malaysia, Sibu-Tinggi are under the state of Johor. The island of Sibu is generally flat, while Tinggi island as the name implies, rises high above the islands cluster and with its highest peak reaching 606 metres high from the sea level. The cone shape peak becomes a reference point for sailors sailing the southern sea. The water around Sibu-Tinggi holds secret of sunken treasures. These treasures come in the form of multi habitats such as the magnificent coral reefs, mangrove forests and the highly precious seagrass meadows. This seagrass meadow supports the elusive and highly endangered Malaysian "sea mermaid" also known as *Dugong dugon*, is a marine mammal that can only be found around the Sibu-Tinggi waters. The dugong is a very shy and elusive animal and is threatened with a small population. It is believed that the island of Sibu plays an important area for the dugong breeding and foraging grounds. An urgent and immediate measure that can be undertaken is to extend the marine protected area to include these important sites.

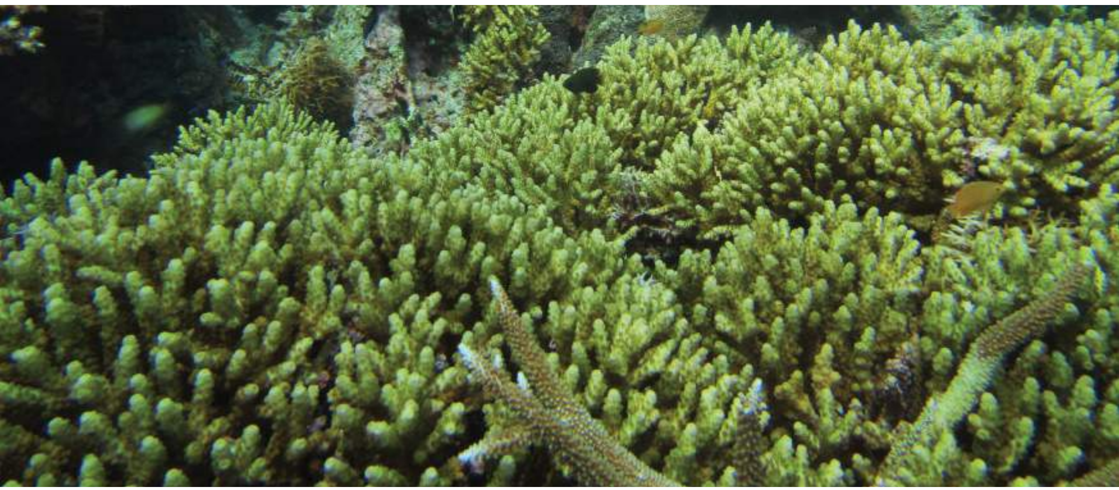
Reef Resilience

Reef health is mainly determined by a reef's "re¬silience", i.e. its ability to resist threats and to re¬cover to its former state after a disturbance has occurred (IUCN, 2011).

Resistance – when exposed to high temperature and other factors, the ability of individual corals to resist bleaching, and if bleached to survive (Obura & Grimsdith, 2009).

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 (Obura & Grimsdith, 2009).

The natural resilience of reefs is being under¬mined by stresses related to human activi¬ties. These local pressures reduce the resilience of the system by undermining its ability to cope with additional stresses, such as those associated with climate change. Increasingly, policy-makers, conservationists, scientists and the broader com¬munity are calling for management actions to re¬store and maintain the resilience of coral reefs in order to minimise the negative impacts of cli¬mate change (**IUCN, 2011**).



Resilience Factors

Resilience refers to the ability of a coral reef to absorb or recover from disturbance and change, while maintaining its functions and services (Carpenter et al, 2001). A reef that tends to return to the same state even after major disturbances has high resilience, while one that shifts into another state has lower resilience. Certain factors can increase the resilience of a coral reef, categorised into ecological and spatial resilience factors. Ecological resilience factors are properties present within the spatial boundaries of the ecosystem; species and functional diversity are included in this context. Spatial resilience factors extend beyond ecosystem boundaries and include large-scale functions and processes, including reproduction and connectivity and shifting geographic ranges (Obura, 2005).

1. Species and Functional Diversity

The main ecological factor that affects coral reef resilience is a balanced biological and functional diversity within the coral reef. It is important to have a balanced ecological community with sufficient species interactions for coral reefs to recover from disturbances (Nystrom & Folke, 2001). An especially important functional group for coral reef resilience is the grazing animal group, consisting of herbivorous fish and sea urchins among others. They increase coral reef resilience by preventing phase shifts from coral dominated reefs to algal dominated reefs by keeping algal growth in check and allowing the settlement of slower-growing coral recruits rather than faster-growing algae (Gabriel & Rodney, 2005). In addition to herbivores, other important functional groups that determine coral reef resilience are (Nystrom & Folke, 2001):

- Reef-building corals and coralline algae (for building the structure)
- Mobile links (species that move between habitats increasing connectivity, e.g. fish often transport zooxanthellae between coral reefs)
- Support areas for mobile links (e.g. seagrasses and mangroves as breeding grounds for fish)

- Predators (these maintain a higher diversity of herbivores and control bioeroder populations)
- Corallivores (these allow the dispersal of coral fragments and zooxanthellae)
- Settling facilitators (bacteria, diatoms, coralline algae and worms that aid larval settlement)
- A framework of dead coral and rubble (this provides habitat complexity and a substratum for recruits)
- Herbivores (these graze algae, thus allowing coral recruits to settle and grow)

Functional diversity and ecological interactions between these functional groups can be severely compromised by human disturbance. As a result, ecosystem resilience, services and productivity can be reduced, resulting in even greater impacts of subsequent disturbances. If the difficulties for one species to replace another even ecologically-similar one in the functional framework of an ecosystem were taken into account, the loss of even just a single species can often lead to ecological changes that are irreversible in the short-term (Nystrom & Folke, 2001).

2. Reproduction and Connectivity

An important spatial factor for coral reef resilience is the connectivity between and within coral reefs. Coral's large populations and discharges of larvae create high genetic diversity that is crucial for resilience against disturbance (Nystrom & Folke, 2001). Coral larvae are poor swimmers and need to be carried by water currents to settle on reefs, but they can travel thousands of kilometres, meaning that even remote coral reefs can be interconnected (Chia et al, 1984). Therefore upstream, larval exporting 'source' reefs with diverse populations of healthy adult corals are crucial to maintain the genetic diversity and resilience of downstream, larval-importing 'sink' reefs. Unfortunately, large-scale mortality on a coral reef reduces its capacity to self seed, so it is important that healthy corals produce abundant and robust larvae that reach the degraded reefs and then settle and grow. It is thus important to identify and protect source reefs and the ocean currents connecting them to sink reefs (Nystrom et al, 2000).

The mode of reproduction of corals also determines the range within which they can repopulate other reefs: asexually-reproducing corals (from coral fragments) disperse locally while sexually-reproducing corals (from larvae) can disperse over much larger distances (Nystrom & Folke, 2001). In addition to good connectivity, appropriate substrates are also very important for larval settlement. A framework of dead coral or surfaces of calcareous algae provide the best substrates for coral recruitment. Good substrates should be stable and surrounded by calm waters with salinity levels between 32‰ and 40‰, and they should have a good light source, a lack of macroalgae, appropriate grazing levels and limited sedimentation (Richmond, 1993). Encrusting coralline algae that aid settlement and growth of coral recruits also contribute to strong recruitment (Buddemeier et al, 1993). Because of the various substrate types, the varying connectivity, the varying environmental conditions and the different species involved, coral reef recovery from disturbances through re-colonisation and re-growth can vary greatly spatially and temporally (Gleason, 1996).

3. Shifting Geographic Ranges

Another interesting spatial resilience factor is the possibility that global changes in climate will promote the growth of coral reefs in marginal areas of the present range of coral reef distribution. As the climate in present geographical ranges becomes less favourable, the diversity of coral reefs in presently marginal areas could increase. However, according to Buddemeier et al. (2004), 'geographic shifts of coral reefs would not lessen the ecological and economic problems caused by the loss of tropical reefs, but it would partly lessen concerns about global biodiversity loss.' However, conditions today are not as favourable for shifts in geographic ranges as they were in the past because:

- Given the present high sea-level stand, projected sea-level rise is small compared to the rise that occurred during the past when the large rise in sea-level aided shifts in geographic ranges
- Areas where coral recruits attempt to settle today are hugely impacted by human disturbances and are thus not always suitable for colonisation (Hughes et al, 2003).

Overall, there seems to be little research into the possibility of climate-induced shifts in the geographic ranges of coral reef species. Sources that do mention the phenomenon usually examine past examples rather than future possibilities. Possible future research could involve identifying potential areas into which species could extend their ranges and the development of programmes to monitor such shifts. If the extension of geographic ranges becomes an apparent trend, appropriate management initiatives could be put in place in the new 'sink' areas. It could be possible to ensure optimal conditions for coral recruitment and growth in the new areas, or, conversely, to implement suitable management strategies if these coral reef species become problematic invasive species (Gabriel & Rodney, 2005).

Methodology

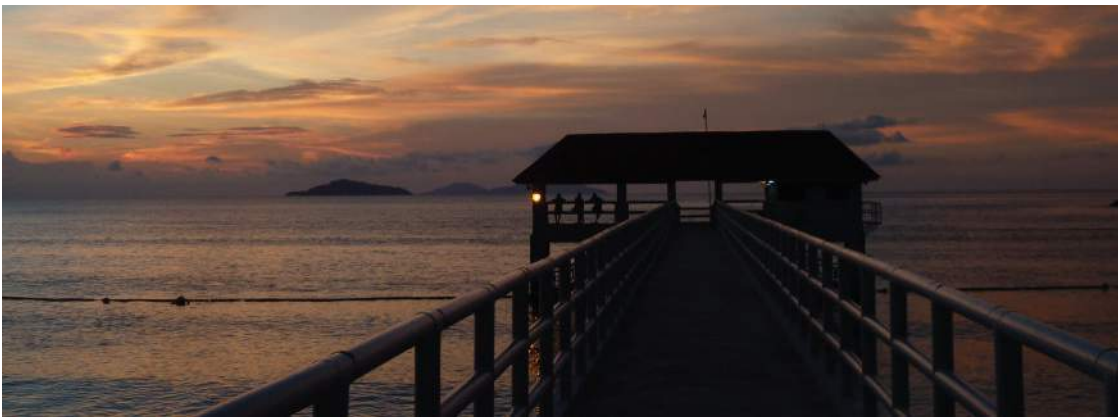
This Coral Reef Resilience Assessment Methodology is an initial attempt to provide information on the resilience of coral reefs in Malaysia, and how to incorporate resilience information into coral reef management.

Resilience assessment methods were initially developed by the IUCN working group on Climate Change and Coral Reefs, specifically to examine the resilience of coral reefs to climate change, with particular emphasis on thermal stress.

The methodology described here is adapted from Obura, D.O. & Grimsditch, G. (2009) Resilience Assessment of coral reefs – Assessment protocol for coral reefs, focusing on coral bleaching and thermal stress and has been modified to the needs of reefs in Malaysia.

Site selection

Careful site selection is essential in order to cover a broad range of sites in terms of health, reef habitat and zone as well as potential influence of the factors that may affect coral bleaching and recovery. The goal is to survey two depth contours, recognising 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. In this assessment, sites were selected at approximately 3-5 m. However, on some reefs, the highest coral cover was not found at these exact depths, and adjustments were made.



The basic selection criteria considered in this assessment were:

1. Depth – include shallow (< 5 m) and deeper (operationally 10-15 m, as deeper than that time restrictions severely limit sampling ability. With more 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.

Benthic Surveys

Substrate Cover

Point Intercept Transect

- Two 25 m transects and taking point count at every 25 cm
- Four categories of data were recorded:
    - o Inverts – (HC, SC, SP, RKC)
    - o Algae – (Fleshy algae, Turf algae, Coraline Algae, Halimeda
    - o Substrate – (RC, RB, SD, SI)
    - o Others – (Seagrass, Unidentified)



Coral Size Class

Belt Transect
• Two 25 m x 1 m transects
• Number of coral colonies above 10 cm in size was counted
• Size of largest coral was recorded

Quadrat
• 1 m x 1 m quadrat at every 5m along a 25 m transect (two 25 m transects)
• Number of coral colonies less than 10 cm in size was counted

Fish Surveys

Abundance and Biomass

Belt Transect
• One 50 m x 5 m belt transect along depth contour parallel to reef
• Numbers and length of indicator species were recorded
• Fish size is recorded to nearest 5 cm (e.g. 0-5 cm, 5-10 cm, 10-15 cm, ...)
• Minimum size is 10 cm except for angelfish (small species)
• Indicator species: Surgeons, Batfish, Angels, Parrotfish, Rabbits, Sharks, Groupers, Snappers, Sweetlips, Jacks and Barracuda

Off Transect
Indicator species larger than 30 cm is recorded

Resilience Factors

In Situ

50 m x 1 m belt swims at same depth parallel to the shore. The following were observed and recorded based on 5 point scale. See datasheet in Appendix 1.

1. Depth
2. Visibility
3. Temperature & thermoclines according to depths (if present)
4. Signs of coral disease
   - Disease prevalence at sites. Number of corals with disease within transects
5. Sand size/sediment texture
   - Texture and nature of sediment, from fine terrestrial to coarse carbonate
6. Trash/solid pollution
   - Presence of solid waste and impacts on reefs
7. Physical damage
   - Signs of physical damage and impact on reefs
8. Turbidity/sedimentation
   - Turbidity/sedimentation cause by human activities
9. Topology complexity
   - Micro-complexity: complexity on recruitment scale
   - Macro-complexity: complexity on large body scale
10. Physical shading
    - Subjective shading by topographical features e.g. columns and overhangs
11. Coral canopy
    - Degree of multistory canopy in coral community
12. Bioeroders and corallivores
    - External Bioeroders. Abundance/prevalence of bioeroders & scrapers (non fish)
    - Internal Bioeroders. Abundance/prevalence of bioeroders
    - Corallivores. Abundance/prevalence of corallivores
13. Destructive fishing
    - Use of destructive fishing methods and its impacts on reefs

On Land Surveys

Research or oral communication was used. See data sheet in Appendix 2.

1. Exposure during low tides /spring tides
   - Aerial exposure of corals during low/spring tides & effects on shallows

2. Ponding/Pooling
   - Degree of isolation/ponding of shallow water during low tide, exposure to water that has heated during low tide

3. Survival of past bleaching
   - Evidence of corals having survived recent bleaching events

4. Trash/solid pollution
   - Presence of solid waste and impacts on reefs

5. Chemical pollution
   - Extent of anthropogenic pollutants

6. Fishing pressure

7. Dispersal barriers
   - Presence and scale of dispersal barriers

8. Management
   - Biodiversity. Degree of management with biodiversity objectives
   - Resources. Degree of management with resource use imitation/ control objectives
   - Environmental quality. Degree of management with environmental quality objectives (pollution/ICZM)

9. Wave energy/ exposure
   - Wave energy & exposure to wave generating weather

10. Currents
    - Local exposure of site to moving water

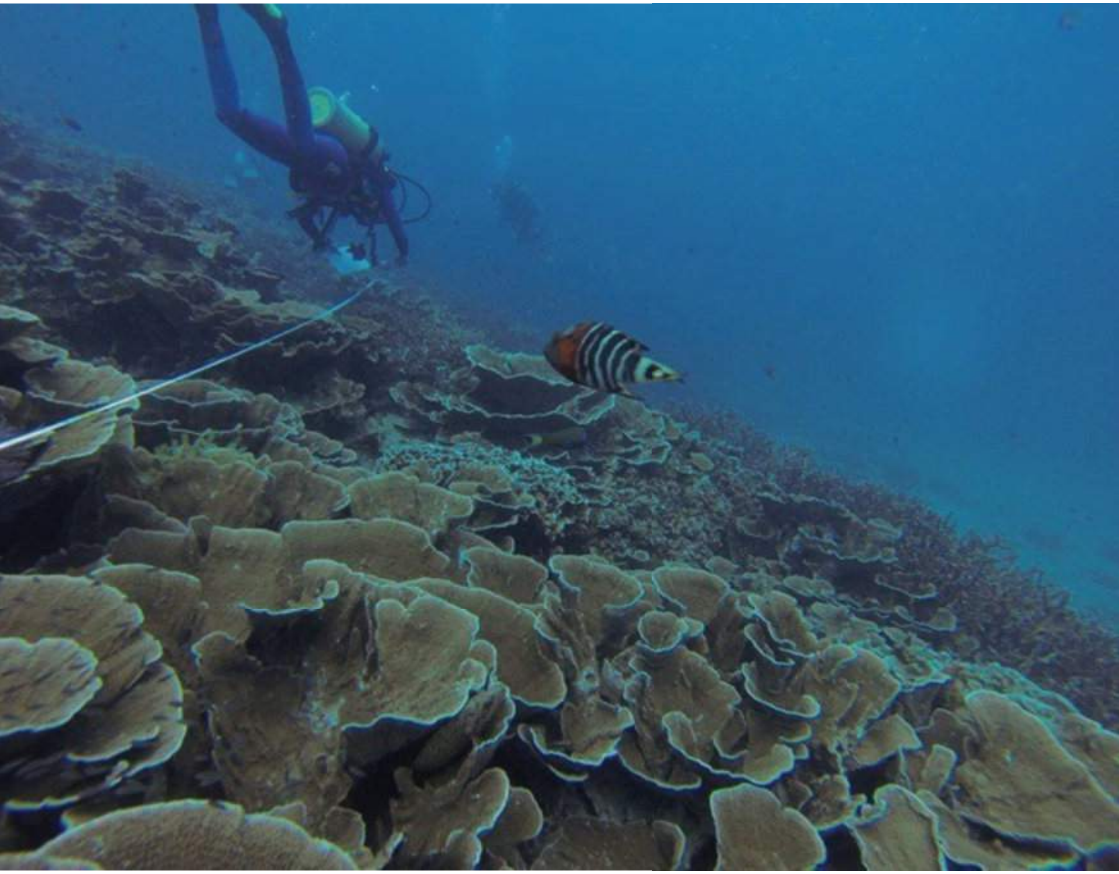
11. Deep water
    - Proximity to 30 -5 0m on reef front

12. Connectivity

- Dispersal
- Self seeding- connectivity at local scale of 1 km reefs
- Local seeding (10 km) – connectivity at between-reef scale of about 10 km
- Distant seeding (100 km)- connectivity at regional scale >100 km
- Transport
- Currents – current flow orientation and dynamics relative to coastline/ reefs

13. Destructive fishing

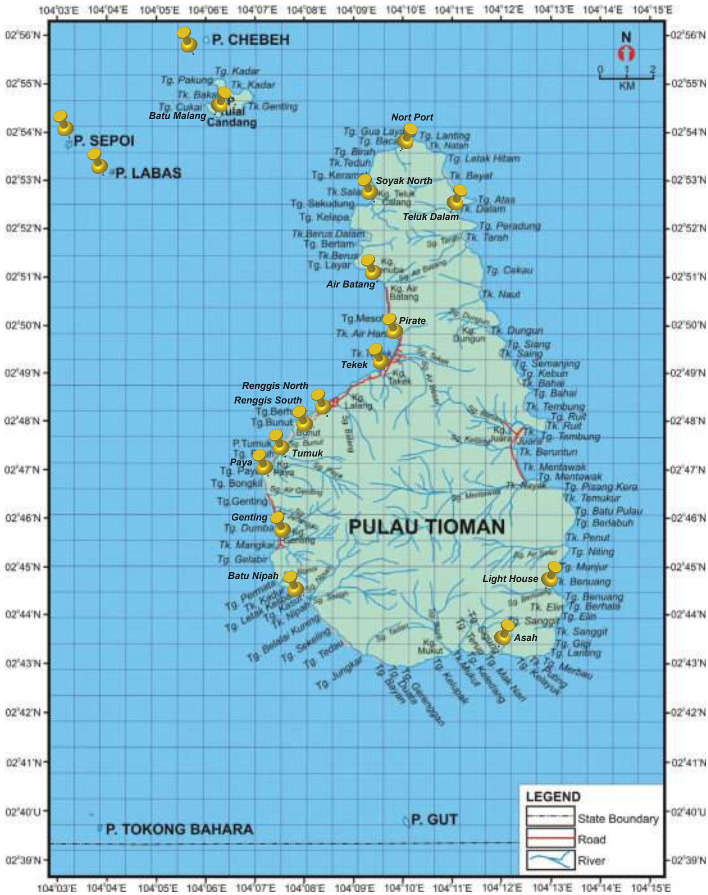
- Use of destructive fishing methods



Results & Discussions

Tioman Archipelago

A total of 18 sites (Map 1) were surveyed around the Tioman archipelago and these sites were chosen based on local knowledge of reef areas as well as random sampling. Reefs from the Southeast end of the island to the Northeast tip were surveyed to give a clear and fair representation of the most resilient reefs. Survey results showed that the most resilient reefs were located in the Northwest of the archipelago. Table 1 summarises the data for each site and the complete data sheet is shown in Appendix 3.



Map 1: Surveyed sites in Tioman archipelago

Table 1: Surveyed sites and respective resilience score for Tioman Archipelago (from highest to lowest)

Site	Coordinates	Score
Renggis North	02' 48.607 104' 08.185	56.5
Renggis South	02' 48.496 104' 08.042	53.0
Soyak North	02' 52.554 104' 08.864	52.5
Chebeh	02' 56.052 104' 05.842	49.0
Teluk Dalam	02' 52.456 104' 11.254	48.5
Lighthouse	02' 43.927 104' 13.021	48.0
Pirate	02' 49.421 104' 09.453	46.0
Malang Rock	02' 54.227 104' 06.245	45.5
North Point	02' 53.606 104' 09.418	42.5
Sepoi	02' 53.530 104' 03.600	42.0
Labas	02' 53.223 104' 03.941	37.5
Asah	02' 43.143 104' 11.970	33.5
Tumuk	02' 47.575 104' 07.378	33.0
Batu Nipah	02' 43.927 104' 08.119	31.0
Paya	02' 47.205 104' 07.124	27.0
Tekek	02' 49.051 104' 09.046	23.0
Genting	02' 45.759 104' 07.247	21.0
Air Batang	02' 50.672 104' 09.538	14.5

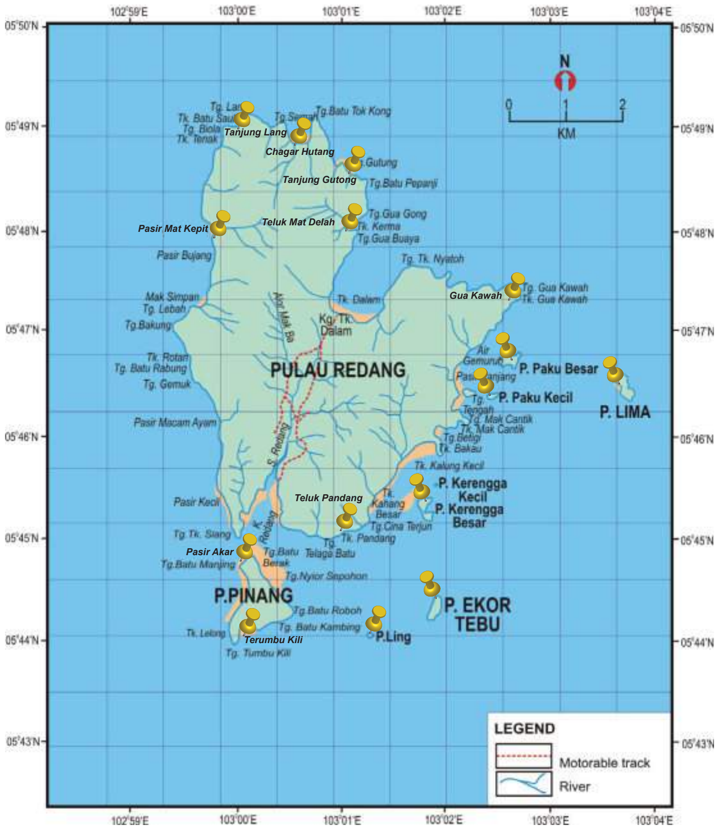
Renggis North, Renggis South and Soyak North recorded the highest resilience scores. The key resilience factors are considered to be:

1. Very high levels of live coral cover, indicating healthy reef environments. Soyak also has very high diversity of coral species.
2. High topographical complexity at both micro and macro levels. Reefs at these locations are highly rugose (having a complex 3-dimensional structure), providing vast areas for coral recruitment and a range of habitats for marine life.
3. Canopy corals and physical shading are abundant, adding to rugosity and providing areas in which water is likely to be cooler.
4. Healthy fish populations, with high numbers of predators and above average numbers of herbivores.
5. High recovery rates from previous bleaching events.

Air Batang, Genting and Tekek, which scored lowest on the resilience scale, showed lower recovery from previous bleaching event, higher physical damage, and higher amounts of rubble, algae and silt. It is no surprise that these sites also scored poorly on hard coral cover and fish counts. These three sites are popular tourist destinations and most of the resorts on Tioman are located in these areas. The effects of tourism on these reefs are clear to see.

Redang Archipelago

A total of 15 sites (Figure 2) were surveyed around the Redang archipelago. Once again site selection was based on local knowledge and random sampling. Results showed that the Northern part of the island, which is furthest from village and tourist influence, scored the highest. A summary for each site is shown in Table 2 and the complete data sheet is shown in Appendix 3.



Map 2: Surveyed sites in Redang archipelago

Table 2: Surveyed sites and respective resilience score for Redang Archipelago (from highest to lowest)

Site	Coordinates	Score
Teluk Mak Delah	05' 47.986 103' 01.019	64.5
Tanjung Gutong	05' 48.455 103' 01.062	64.0
Gua Kawah	05' 47.413 103' 02.327	62.5
Chagar Hutang	05' 49.083 103' 00.597	62.0
P. Ling	05' 43.998 103' 01.182	60.5
P. Paku Kecil	05' 46.301 103' 02.324	60.5
Teluk Pandam	05' 45.040 103' 00.991	58.5
P. Lima	05' 46.451 103' 03.526	57.0
P. Kerengga Besar	05' 45.242 103' 01.740	55.5
Tanjung Lang	05' 48.891 102' 59.744	51.5
Terumbu Kili	05' 43.928 102' 59.825	48.5
Pasir Akar	05' 44.398 102' 59.955	47.0
P. Paku Besar	05' 46.654 103' 02.612	47.0
P. Ekor Lembu	05' 44.283 103' 01.730	36.5
Pasir Mak Kepit	05' 47.778 102' 59.655	22.0

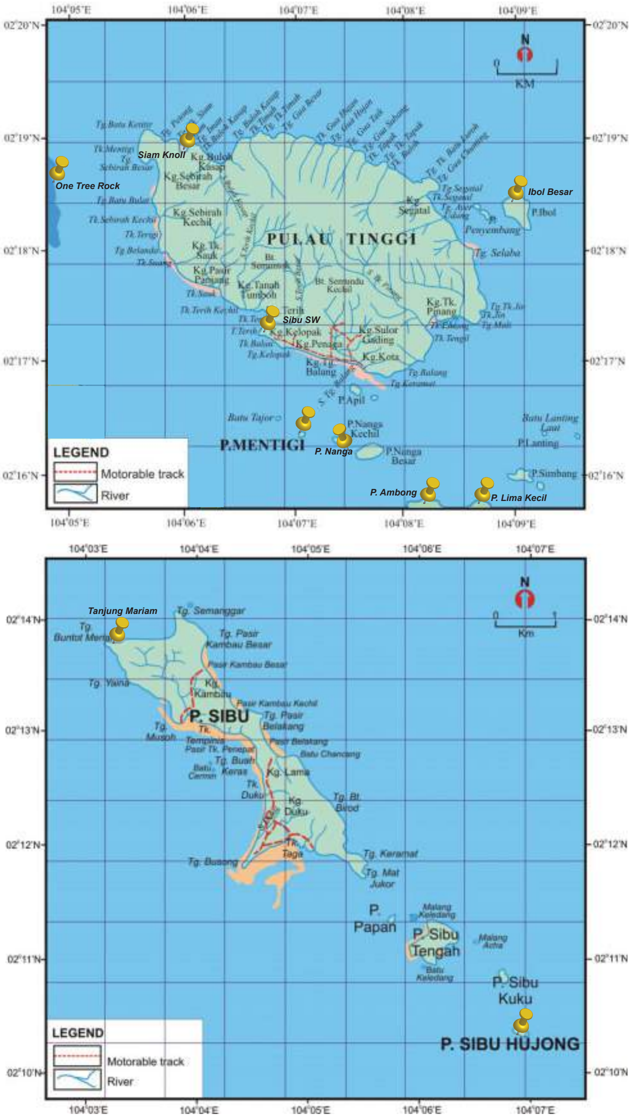
Teluk Mak Delah, Tanjung Gutong and Gua Kawah recorded the highest resilience scores in Redang. The key resilience factors are considered to be:

1. Above average levels of live coral cover, indicating healthy reef environments.
2. Diverse coral populations with high levels of recruitment of new coral colonies and wide variety of colony size.
3. High topographical complexity at both micro and macro levels. Reefs at these locations are highly rugose (having a complex 3-dimensional structure), providing vast areas for coral recruitment and a range of habitats for marine life.
4. Near to deep water and strong currents, which enhance mixing of water and help to keep water temperature low .
5. Moderate abundance of canopy corals and physical shading, adding to rugosity and providing areas in which water is likely to be cooler.
6. Moderate recovery rates from previous bleaching events.

Pulau Paku Besar, Pulau Ekor Lembu and Pasir Mak Kepit scored lowest among the 15 sites surveyed. These sites showed signs or physical damage, disease, high competition with algae, and high mortality. High amounts of silt and rubble were also recorded at these sites which would further deter coral settlement and growth. These reefs also lacked variety in coral size.

Sibu – Tinggi Archipelago

A total of 10 sites (Map 3) were surveyed around the Sibu – Tinggi archipelago. A summary of the survey results are shown in Table 3 and the complete data is shown in Appendix 3.



Map 3: Survey sites around Sibu – Tinggi Archipelago

Table 3: Survey sites and respective resilience score for Sibu – Tinggi Archipelago (from highest to lowest)

Site	Coordinates	Score
Ibol Besar	02' 18.180 104' 08.940	53.0
Tanjung Mariam	02' 13.860 104' 03.130	51.5
Nanga	02' 16.270 104' 07.640	50.5
Siam Knoll	02' 19.032 104' 05.646	48.5
One tree rock	02' 16.377 104' 02.130	48.0
P. Lima Kecil	02' 13.336 104' 08.943	43.5
Mentinggi	02' 16.400 104' 06.940	42.0
P. Ambong	02' 13.399 104' 08.109	35.5
P. Sibu Hujung	02' 10.876 104' 06.709	28.5
Sibu SW	02' 17.070 104' 06.748	25.5

Pulau Ibol Besar, Tanjung Mariam and Pulau Nanga scored the highest resilience totals in the Sibu – Tinggi archipelago. The key resilience factors are considered to be:

1. On all three sites coral cover is high and algae cover is low, indicating healthy reef environments.
2. The diversity of corals, as well as the range of coral colony size, is high at Tanjung Mariam and P.Nanga.
3. Pulau Nanga recorded the highest amounts of coral recruits while P. Ibol Besar and Tanjung Mariam recorded high reef complexity and high levels of natural shading. P. Ibol Besar is unique as it has a steep sloping reef which provides more natural shading from direct sunlight. There is also evidence of good recovery from past bleaching events. Other competitors were also scarce.
4. There are high numbers of herbivorous fish in P. Ibol Besar and high numbers of piscivores in Tanjung Mariam.

Pulau Ambong, Pulau Sibu hujung and Sibu SW scored lowest. All three sites have high rates of mortality, low coral cover, and high amounts or rubble, silt and algae.

Preliminary Conclusions & Recommendations

These preliminary conclusions and recommendations have been prepared in order to provide an initial input to DMPM's management planning process. More detailed analysis of the data collected is required to prepare detailed recommendations for managers at each site.

The data collected identifies the most resilient coral reef areas at each site. In the context of building resilience to global threats (climate change and ocean acidification) managers should consider ways to improve management of these areas.

Comparisons of site resilience information are only valid for sites around a given island/archipelago. Conditions differ significantly between islands (eg. water quality and visibility; tourism market and impacts) and therefore comparisons of resilience information for sites on different islands does not provide useful guidance to managers.

Local threats are considered to be substantially the same in each location. The principal threats identified are:

Land use change

Tourism development in all three locations has resulted in damage to coral reefs, particularly close to tourist beaches. Land clearing for resort development releases silt into the sea, smothering and killing corals; poor waste management practices result in trash collecting on beaches and reefs.

Sewage pollution

The remote location of these islands (distant from mainland Malaysia) strongly suggests most pollution on the islands' reefs is from the islands themselves. Key among pollution sources is sewage pollution. None of the islands has centralised sewage treatment facilities and few resorts have secondary sewage treatment systems. Furthermore, there are no programmes to maintain septic tanks nor provide de-sludging services. As a result, effluent from the limited treatment facilities that are in use is high in nutrient, which encourages algae growth on reefs which competes with corals for space and sunlight. There is also a public health issue to be addressed.

Physical impacts

These range from damage caused by individual divers and snorkelers through to the impact of construction of tourism facilities such as jetties. Despite bans on use of anchors, in some areas boatmen do still use anchors, another source of physical damage. On its own, this threat is unlikely to cause significant damage to reefs (except in some heavily used dive and snorkel sites). However, in combination with the above impacts the cumulative impact is significant.

Strengthening of enforcement

In some areas, more enforcement need to be created where present conditions in which illegal fishing (either from jetties or trawling) is still happening, divers and snorkelers are not properly well supervised, and boats anchor illegally.

Preliminary recommendations are as follows:

Zoning

It is recommended that DMPM consider introducing "zoning" into the existing management structure of the Marine parks. This would allow managers to create zones of higher conservation value, and would create the opportunity to more easily close or otherwise actively manage selected reef areas. It is worth noting that in many cases, where a resilient reef area has been identified, it is part of a wider reef system and closing the most resilient area will not necessarily require closure of the entire reef site. Careful communication (see below) of this to dive and snorkel operators can create "win-win" situations in which both management and user agree to reduce activities in selected parts of a reef site, but still have the use of the wider site.

Sewage treatment

Most resort operators on the islands that were part of this study lack adequate sewage treatment facilities. Most rely on septic tanks which, if properly managed and maintained are considered suitable. It is recommended that DMPM work together with local authorities and IWK to implement a programme of septic tank de-sludging and maintenance to ensure that these facilities are operating efficiently. RCM has prepared a separate report on this issue.

Management of development/construction

It is recommended that DMPM work together with relevant local authorities to improve management of development on the islands. In particular, where resilient areas might be affected by development proposals, DMPM should carefully assess any proposals for new resorts/tourism facilities to ensure that these critical areas are protected to the fullest extent possible.

Awareness

Despite numerous campaigns promoting coral reef conservation, awareness among resort and dive operators about coral reef issues is still low. The resilience findings provide a platform to address this problem, and to establish a better dialogue between DMPM and tourism operators (both island-based and inbound providers). Workshops, publicity campaigns and information displays should be utilised to raise awareness of the importance of coral reefs and how all tourism operators can play a role in reducing damage and protecting resilient areas.

Capacity building for DMPM staff

It is recommended that DMPM staff (both at headquarters and island-based) are to be briefed on the findings of the resilience assessment, so that they develop a better understanding of the threats facing coral reefs. Headquarter staff have the opportunity to affect management policy to give greater protection to resilient areas; island-based staff should be able to communicate effectively the need to protect resilient areas while undertaking enforcement and educational activities.

Detailed assessment studies

The methodology used here provides a preliminary assessment of resilient areas on the islands studied. However, a more detailed assessment is required to better understand, for example, the impact of improving fish populations or the importance of coral diversity. In addition, large areas of coral reef have not yet been assessed, and these areas need to be included in further studies.

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Appendix 1

Factor/ Variable	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Substrate & Morphology: Micro complexity	Smooth surfaces	Rough textured surface to 1cm texture	Moderate micro-scale structure/crevices	Diverse 3D spaces to 10cm	Deep intricate branching/interlocking framework to 10cm
Substrate & Morphology: Macro complexity	Flat	Corals/relief 1-10 cm texture	Coral/crevices about 0.5-1m relief, separated by >5m	Corals/relief 1-2m some development of structure-bommies etc 3-6m apart	Major spur/groove/heads >2 relief, pillars/caves and swim throughs
Substrate & Morphology: Sediment texture	None	Coarse Carbonates	Coarse - Fine sand	Fine Sand	Fine silt/ high organic content
Substrate & Morphology: Sediment layer	None	Very fine/interspersed	Few millimetres in patches <20% cover	Embedded in algal filaments, thin	Several millimetres, embedded in algal filaments, invading coral edges
Physical Shading	None	Some shading from vertical/thin structures	Moderately developed columnar forms & vertical faces on bommies	large vertical faces in multiple directions/ complex faces causing variable shading	Overhangs/ above water shading
Canopy Corals	None	Minor shading by some erect corals	Moderate coral community at multiple levels	Over branching of canopy corals	Extensive over branching of canopy corals
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
Mortality – recent	None	Minor background/normal bleaching, <10%	Moderate levels of mortality, < 25%	High levels of mortality, about 50%	Very high levels of mortality, > 75%
Coral Disease	None	< 5 (1 per 25x1m)	10-15 (2-4 per 25x1m)	> 30 or 10% population (20 per 25x1m)	Predominance of disease large proportions of colony affected
Mortality – old	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%
Recovery – old	No recovery at all, full extent of mortality visible	Some recovery, adding back 10 (25)% of pre-existing community	30 (50)% recovery	50-75 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

Factor/ Variable	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Dominant size class	All corals small, <20cm	Mostly small/medium corals, no large ones, few moderate-large ones	Mid-size classes abundant, but very few large ones. Over-dominance of few sizes	Many large corals, or intermediate-large	Full range of size classes, with may in mid-sizes and diverse large corals
Competitors	None	Low-potential competitors present, but interactions not prominent	Competitors present and interactions commonly seen, only slightly detrimental	Clear competition for space, with evidence of negative impacts on corals	Competitors abundant, clear negative impacts on corals from competitors
Bioeroders – external	None	Present, low numbers & interactions not prominent	Common & interactions/ impacts seen, only slightly detrimental to corals/benthos =1m2	Clear bioerosion happening, moderate negative impacts on corals/benthos = 5m2	Abundant, clear negative impacts on corals/benthos >10m2
Bioeroders – internal	None	Present, low numbers & interactions not prominent	Common, interactions impacts seen, only slightly detrimental to corals/benthos	Clear bioerosion happening, moderate negative impacts	Abundant clear negative impacts
Corallivores (negative)	None	Present, low numbers, interactions not prominent. No or very minor predation seen	Common, interactions/impacts seen only slightly detrimental to corals (up to 5 corals)	Clear predation happening moderate negative impacts on corals 10-30 dead corals	Abundant, clear negative impacts on corals 50+ dead corals
Solid Pollution	Occasional pieces. No impact	Some trash, smothering/ impact	-	Abundant trash wrapped in corals	-
Turbidity/ Sedimentation	Some influence likely, minor affect	Natural high sediment regime, increased by anthropogenic activities	Sediment regime strongly altered/worsened by anthropogenic activities	Near-total. Almost all high turbidity/sediment due to anthropogenic sources	-
Physical Damage	Some damage, no impact	Some damage, impact at low levels	Damage clearly important part of mortality but minor decline in coral cover	Very high, clear evidence of disturbance and high mortality	-
Destructive fishing	Some use but at too low levels to show any impacts	Frequent use, some evidence of mortality/damage but low compared to natural levels	Frequent use, clear evidence of mortality/damage	Extensive use, clear impact on coral mortality and substrate	-

Appendix 2

Factor	Quantity	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Currents	Local exposure of site to moving water	None/ Very Low	Low/ General background conditions, nothing	Linear reef edges & structures exposed to general water flow up	Reef edges/points & more complex features in flow conditions	Tidal Channels, pinnacles/ patches in high flow areas, major
Wave energy/ exposure	Wave energy & exposure to wave generating weather	Zero- all non-wave zone sites, fully sheltered	Indirect/ dissipated exposure to wind/ swell	Evidence for wave influence. But not extreme, presence of some branching corals, not direct face onto winds/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
Deep Water (30-50m)	Proximity to 30-50 m on reef front	30-40	40-50	50-60	60-70	>70
Exposed low tide	Aerial exposure of corals during spring low tides - effects of shallows	None/ Very Low	One or two isolated heads	Yes, small portion/ area of community	Yes	Yes, significant portion of community
Ponding/ pooling	Degree of isolation/ ponding of shallow water during low tide, exposure to water that has heated at low tide - effect of enclose/ 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 water (eg. Reef edges off large shallow banks)	Intricate/ reticulate reef systems impending circulation	Frequent occurrence during all low tides, complete isolation of small bodies of water for some hours
Survival of past bleaching events	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
Self-seeding	Connectivity at local scale of 1km reefs	Reef size on scale of 10s of m separated by >1km of poor habitat	Reef patches on 100s of m scale, separated by larger distances of poor habitat	Patchwork of coral communities on 100s of 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 km

Factor	Quantity	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Local seeding (10 km)	Connectivity at between-reef scale of about 10 km	Nearest reef structures >10 km distances	Reef structures on 1 km scale, but widely separated 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 10s of km
Distant seeding (100km)	Connectivity at regional scale >100 km	Nearest reef system >100 km away	Isolated reef areas, some 20-80 km apart	Patchwork of local reef systems dispersed over area 100s of km in extent. Separated by poor habitat	Larg reef systems over 100-200 km extent occupy 50-80% of space	Extensive reef province 100s of km in extent in multiple directions
Currents	Current flow orientation & dynamics relative to coastline/ reefs	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/ bidirectional flow	Complex eddies and circulating currents
Dispersal barriers	Presence & scale of dispersal barriers	None	-	-	-	> 200km open water & poor environmental quality
Solid Pollution	None	Occasional pieces of waste/ trash. No impact on community	Some trash, smothering/ impact	-	Abundant trash wrapped in corals	-
Fishing pressure	None	Low pressure. Carnivore target species but low impact	Moderate pressure but sustainable catch. Good fish population in water, few large individuals	Population depleted; no large individuals. Catch mainly small/ medium individuals	Very high depletion of fish carnivores/ piscivores. Catches small sizes	Verify with fish monitoring data
Destructive fishing	None	some use but at too low levels to show any impacts	Frequent use, some evidence of mortality/damage but low compared to natural levels	Frequent use and clear evidence of mortality/damage	High very extensive use with clear impact on coral mortality and substrate	Verify with fish monitoring data
Biodiversity Management	Degree of management with biodiversity objectives	None	Some actions present, low level intervention. Some raised awareness	Moderately effective. Interventions limit disturbance but impacts visible	Effective reasonable levels of compliance. High awareness/ no risk of genetic loss	Very high/ fully effective. No loss of species

Factor	Quantity	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Resources Management	Degree of management with resource use limitation/ control objectives	None	Some action/ presence. Low level of intervention. Some raised awareness	Moderately effective, interventions limit disturbances but impacts still visible	Effective reasonable levels of compliance. High awareness/ resource populations moderately impacted	Very high/ fully effective control or resource extraction protecting stock integrity and population dynamics
Environmental Quality Management	Degree of management with environment. Quality objectives.	None	Some action/ presence. Low level of intervention. Some raised awareness	Moderately effective, interventions limit disturbances but impacts still visible	Effective reasonable levels of compliance. High awareness/ environment quality only slightly compromised	Very high/ fully effective control of pollution and other disturbances to water and substrate quality

Appendix 3

Resilience factors and scores for survey sites around Tioman archipelago

			Direction	Tioman Island																	
				Malang	Chebeh	T Dalam	N Point	Soyak	Nipah	Lighthouse	Asah	Genting	Payar	Tumuk	enggis Nor	enggis Sou	Pirate	Air Batang	Tekek HR	Sepoi	Labas
1. Benthic	Coral	Hard Coral	+	3	4	3	3	4	4	4	3	4	5	4	5	4	5	1	3	2	2
		Soft Coral	+	2	1	1	2	1	1	4	5	1	1	1	1	1	1	1	1	1	3
	Algae	Fleshy Algae	-	-1	-1	-4	-1	-2	-3	-1	-5	-2	-3	-4	-2	-2	-4	-1	-3	-4	-2
	Substrate	Rubbel/substrate stablity	-	-1	-4	-1	-2	-1	-1	-1	-1	-4	-1	-2	-2	-2	-1	-4	-5	-1	-5
2. Physical	Substrate & morphology	Topographical complexit	+	5	5	4.5	3	5	4	3.5	3	3.5	3.5	4.5	5	4	4	2	3.5	4	3
		Topographical complexit	+	4	3	4	4	5	1	3	3	3	2.5	4	4	3.5	4	3	3.5	4	3
		Sediment texture	-	-2	-1	-1	-2	-1	-3	-3	-1	-3	-3	-2	-1	-1	-4	-3	-3	-1	-3
		Sediment layer	-	-2	-1	-1	-1	-1	-2	-2	-1	-3	-2	-3	-1	-1	-3	-2	-3	-2	-2
	Cooling & Flushing	Temperature	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Currents	+	4	4	2	2	3	2	2	2	2	2	2	3	2	3	2	2	4	3
		Wave energy/exposure	+	5	5	5	4	3	3	5	5	3	3	3	3	3	2	2	2	5	5
		Deep water (30-50m)	-	5	5	5	5	3	1	5	5	1	1	1	3	3	3	3	1	5	5
		Depth of base of reef	+	5	5	1	1	3	1	1	1	1	1	1	3	3	3	1	1	5	5
	Shade & Screen	Depth	+	3	5	3	3	3	3	5	3	3	1	5	3	3	5	1	3	3	5
		Visibility (m)	-	-1	-1	-2	-2	-2	-2	-5	-2	-1	-2	-1	-1	-2	-2	-1	-1	-5	-3
		Compass direction/aspec	+	3	3	3	1	3	3	3	1	3	3	3	3	3	3	3	3	3	1
		Slope (degrees)	+	2	5	2	4	3	2	2	1	1	1	2	3	2	3	1	1	5	2
		Physical shading	+	4	2.5	3.5	3.5	4	2	1.5	2	2	2	3	4	3	4	1	3.5	4	2
		Canopy corals	+	3	3.5	4	2	5	4	1	2.5	2.5	2.5	3	5	4	4	2	3.5	2	2
	Extremes & Acclimatisatio	Temperature variability	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Exposed low tide	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Ponding /pooling	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Survival of past bleachin	+	3	3	2	2	1	2	2	2	1	1	1	4	4	3	1	1	5	5
3. Coral Condition	Current	Bleaching	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Mortality - recent	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Coral disease	-	-1	-1	-1	-1	-1	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Historic	Mortality - old	-	-3	-3	-3	-2	-2	-3	-2	-4	-4	-3	-3	-2	-2	-3	-3.5	-3	-4	-4
		Recovery - old	+	3	2	3	4	4	3	3	3	2.5	3.5	2.5	4	4	3.5	2	3	2	1.5
4. Coral Population	Population biology	Recruitment	+	2	2	3	4	2	1	4	2	2	1	3	2	2	2	3	3	3	3
		Diversity	+	1	3	5	5	5	1	5	1	3	1	3	1	3	3	3	3	1	5
		Dominant size class	+	3	3	3.5	3	4.5	2	2	2	3	2	3	3.5	3	2.5	2	3	2	2
		Largest corals (3)	+	1	1	1	1	2	4	1	1	2	5	4	5	5	5	1	2	1	2
5. Coral Associates	Negative	Competitors	-	-2	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Bioeroders - external	-	-2.5	-2	-1	-2	-2	-2	-1	-2	-2.5	-2	-2	-3	-2	-2	-2	-2	-3	-2
		Bioeroders - internal	-	-2	-2	-1	-2	-2	-1	-2	-1	-2	-2	-2	-2	-2	-2	-2	-2	-1	-2
		Coralliovores	-	-2	-4	-1	-2	-2	-2	-1	-2	-2	-1	-1	-3	-3	-2	-1	-2	-3	-2

6. Fish Groups	Herbivores	Herbivores	+	3	3	2	2	3	3	3	2	2	2	2	2	3	2	1	2	2	1
	Top Predators	Piscivores	+	1	1	5	1	1	3	3	3	1	1	1	5	5	3	1	1	3	1
7. Connectivity	Dispersal	Self seeding	+	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Local seeding (10km)	+	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Distant seeding (100km)	+	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Transport	Currents	+	3	4	3	3	4	3	3	3	3	3	3	3	3	4	3	3	4	3
		Dispersal barrier	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8. Anthropgenic	Water	Nutrient input	-	-1	-1	-2	-1	-1	-2	-1	-2	-2	-1	-2	-1	-1	-2	-1	-3	-3	-1
		Pollution (chemical)	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Substrate	Pollution (solid)	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Turbidity/sedimentation	-	-2	-2	-2	-2	-2	-1	-1	-1	-1	-1	-2.5	-1.5	-1.5	-3	-3	-2	-1	-1
		Physical damage	-	-4	-3	-4	-2	-2	-2	-2	-4	-4	-2	-3.5	-2.5	-2	-2	-4	-2	-4	-4
	Fishing	Fishing pressure	-	-3	-3	-1	-3	-3	-1	-1	-1	-3	-3	-3	-1	-1	-1	-3	-3	-1	-1
		Destructive fishing	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Connectivity	Dispersal barrier	-	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9. Management	Management	Biodiversity	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Resources	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Environmental quality	+	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
			Total	45.5	49	48.5	42.5	52.5	31	48	33.5	21	27	33	56.5	53	46	14.5	23	42	37.5

Resilience factors and scores for survey sites around Redang archipelago

			Redang														
			Pasir Akar	Terumbu	P. Ekor Le	P. Ling	Tanjung La	Chagar Hu	T. Gutong	Teluk Mat	Gua Kawa	P. Paku Ke	Pasir Mak	P. Kereng	Teluk Pan	P. Lima	P. Paku Be
1. Benthic	Coral	Hard Coral	3	3	3	4	2	2	4	3	4	5	1	3	3	3	2
		Soft Coral	1	2	5	1	1	1	2	2	2	2	1	1	1	1	2
	Algae	Fleshy Algae	-2	-4	-1	-1	-1	-2	-1	-1	-1	-1	-4	-3	-3	-2	-5
	Substrate	Rubbel/substrate stablity	-1	-1	-2	-1	-3	-2	-1	-1	-3	-1	-5	-3	-1	-2	-2
2. Physical	Substrate & morphology	Topographical complexity - mic	4	3.5	3.5	5	4	4	4	5	5	4	2	4.5	4.5	4	3
		Topographical complexity - mac	3.5	3	3	4	3	4	4	5	5	3	2	4	3.5	4	3
		Sediment texture	-3	-1	-3	-1	-1	-1	-1	-1	-1	-1	-3	-2	-3	-1	-2
		Sediment layer	-2	-1	-3	-1	-1	-1	-1	-1	-1	-1	-3	-2	-2	-1	-2
	Cooling & Flushing	Temperature	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Currents	3	4	3	3	3	4	3	3	3	3	3	3	3	3	4
		Wave energy/exposure	5	5	5	5	3	3	4	4	4	5	3	5	5	5	5
		Deep water (30-50m)	1	1	1	1	5	5	5	3	3	3	5	3	1	5	3
		Depth of base of reef	1	1	3	3	1	3	1	1	1	5	1	1	1	5	5
	Shade & Screen	Depth	1	2	2	3	3	4	2	2	2	3	2	2	3	3	5
		Visibility (m)	3	2	1	3	5	3	3	3	3	2	3	4	3	2	2
		Compass direction/aspect	3	1	3	1	3	1	3	3	1	3	3	3	3	3	3
		Slope (degrees)	2	4	2	5	4	4	1	1	1	4	4	1	4	2	5
		Physical shading	2.5	2	2	4.5	2	3	3	4	5	2	1	3.5	3	3	2
		Canopy corals	2.5	2	2	1.5	2	3	3	5	5	2.5	1	5	4	4	1
	Extremes & Acclimatisatio	Temperature variability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Exposed low tide	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Ponding /pooling	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Survival of past bleaching even	3	3	3	3	3	3	3	3	3	5	3	3	3	3	3
3. Coral Condition	Current	Bleaching	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Mortality - recent	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Coral disease	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-5	-1	-1	-1	-1
	Historic	Mortality - old	-3	-3	-4	-2.5	-4	-3	-2	-1.5	-1	-3	-5	-2	-2	-2.5	-4
		Recovery - old	4	2	2	3	2.5	3	3	4	4	4	2	4.5	3	3	2
4. Coral Population	Population biology	Recruitment	3	3	3	3	5	5	4	4	3	3	3	3	3	3	5
		Diversity	2	1	1	4	4	5	3	3	3	1	3	3	4	3	3
		Dominant size class	3	2.5	2	4	2	3	4	5	5	2	1	5	3.5	3	1
		Largest corals (3)	2	5	2	4	1	1	4	3	4	4	1	5	4	1	1
5. Coral Associates	Negative	Competitors	-1	-1	-3	-2	-3	-2	-1	-2	-1.5	-2.5	-3	-3	-3.5	-2	-4
		Bioeroders - external	-1.5	-1.5	-1.5	-1	-2	-1	-2	-2	-1	-2	-1	-2	-1	-2	-2
		Bioeroders - internal	-1.5	-1	-1	-2	-1	-2	-1	-1	-2	-1	-1	-2	-1	-1	-2
		Coralliovores	-1.5	-1	-3	-2	-1	-1	-1	-1	-2	-3	-1	-2	-2.5	-2.5	-2

6. Fish Groups	Herbivores	Herbivores	2	2	1	2	3	3	2	2	2	2	2	2	4	2	2
	Top Predators	Piscivores	2	2	1	1	3	4	3	1	1	3	1	1	5	2	3
7. Connectivity	Dispersal	Self seeding	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
		Local seeding (10km)	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
		Distant seeding (100km)	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	Transport	Currents	3	4	3	3	3	4	3	3	3	3	3	3	3	3	3
		Dispersal barrier	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8. Anthropgenic	Water	Nutrient input															
		Pollution (chemical)	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Substrate	Pollution (solid)	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Turbidity/sedimentation	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Physical damage	-1	-2	-3.5	-2	-4	-3	-1	-1	-1	-2.5	-4	-1	-2	-2	-1
	Fishing	Fishing pressure															
		Destructive fishing	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Connectivity	Dispersal barrier	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9. Management	Management	Biodiversity	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Resources	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Environmental quality	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Total	47	48.5	36.5	60.5	51.5	62	64	64.5	62.5	60.5	22	55.5	58.5	57	47

Resilience factors and scores for survey sites around Sibu – Tinggi archipelago

			Sibu & Tinggi									
			Siam Knoll	Ibol Besar	ne tree ro	Nanga	Mentinggi	P. Sibu SW	. Lima Kec	P. Ambong	Sibu Huju	Tg. Mariam
1. Benthic	Coral	Hard Coral	3	4	4	3	4	1	5	2	3	4
		Soft Coral	1	5	1	1	1	1	1	1	1	1
	Algae	Fleshy Algae	-1	-1	-1	-1	-1	-5	-1	-1	-1	-1
	Substrate	Rubbel/substrate stablity	-4	-1	-2	-4	-2	-2	-3	-5	-1	-1
2. Physical	Substrate & morphology	Topographical complexity - mic	3.5	5	4	3	3	3	4	4	3.5	4
		Topographical complexity - mac	4	3	4	4	3	3	3	3.5	2.5	4.5
		Sediment texture	-2	-1	-3	-3	-1	-5	-5	-2	-5	-5
		Sediment layer	-2.5	-1	-2	-2	-1	-2	-2	-3	-2	-3
	Cooling & Flushing	Temperature	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Currents	3	3	3	3	3	3	4	3	3	3
		Wave energy/exposure	5	4	4	4	4	3	5	5	5	3
		Deep water (30-50m)	3	5	1	3	3	1	5	5	3	1
		Depth of base of reef	5	3	5	5	1	1	1	1	1	3
	Shade & Screen	Depth	5	3	5	5	1	1	1	1	1	3
		Visibility (m)	-3	-3	-3	-3	-3	-1	-5	-3	-3	-1
		Compass direction/aspect	3	3	3	3	3	3	3	3	3	3
		Slope (degrees)	1	5	1	1	5	1	1	1	3	3
		Physical shading	3	2.5	3	3.5	2	3	2	3	2	4
		Canopy corals	3	2	4	3.5	2	2.5	4	3	2.5	3.5
	Extremes & Acclimatisati	Temperature variability	1	1	1	1	1	1	1	1	1	1
		Exposed low tide	1	1	1	1	1	1	1	1	1	1
		Ponding /pooling	1	1	1	1	1	1	1	1	1	1
		Survival of past bleaching even	3	5	3	3	5	3	3	3	3	5
3. Coral Condition	Current	Bleaching	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Mortality - recent	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Coral disease	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Historic	Mortality - old	-2.5	-3	-3	-2.5	-3	-3	-2	-4	-3.5	-3
		Recovery - old	2	3	3	4	3	3	4	2	3	3
4. Coral Population	Population biology	Recruitment	4	3	4	4	2	3	3	3	2	2
		Diversity	5	3	5	5	1	5	3	3	3	5
		Dominant size class	3	2.5	3	4	2	2	3	3	2	4.5
		Largest corals (3)	5	1	1	3	1	3	1	1	1	5
5. Coral Associates	Negative	Competitors	-2	-2	-1.5	-2	-2.5	-4	-1	-2	-2.5	-2
		Bioeroders - external	-2	-3	-2	-2	-2	-2	-2	-2	-2	-2
		Bioeroders - internal	-3	-2	-1	-1	-1	-1	-2	-1	-2	-2
		Coralliovores	-1	-2	-1	-1	-2	-2	-1	-1	-3	-1

6. Fish Groups	Herbivores	Herbivores	2	2	1	1	2	1	4	1	1	1
	Top Predators	Piscivores	1	1	1	1	4	1	1	3	1	3
7. Connectivity	Dispersal	Self seeding	2	2	2	2	2	2	2	2	2	2
		Local seeding (10km)	3	3	3	3	3	3	3	3	3	3
		Distant seeding (100km)	2	2	2	2	2	2	2	2	2	2
	Transport	Currents	3	3	3	3	3	3	4	3	3	3
		Dispersal barrier	1	1	1	1	1	1	1	1	1	1
8. Anthropgenic	Water	Nutrient input										
		Pollution (chemical)	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Substrate	Pollution (solid)	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
		Turbidity/sedimentation	-2	-2	-2	-2	-2	-2	-1.5	-2	-2	-4
		Physical damage	-3	-3	-2.5	-2	-1.5	-2	-2	-2	-3	-1
	Fishing	Fishing pressure										
		Destructive fishing	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
	Connectivity	Dispersal barrier	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
9. Management	Management	Biodiversity	1	1	1	1	1	1	1	1	1	1
		Resources	1	1	1	1	1	1	1	1	1	1
		Environmental quality	1	1	1	1	1	1	1	1	1	1
		Total	48.5	53	48	50.5	42	25.5	43.5	35.5	28.5	51.5


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