Assessing coral resilience and bleaching impacts in the Indonesian archipelago

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REEF CHECK

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Cover image caption:

Reefs (top image) are dynamic systems that are regularly disturbed by impacts like coral bleaching (right and bottom image), and severe storms. The natural resilience of reefs enables them to recover following such disturbances. Their ability to recover (left image) though depends on: the frequency and severity of disturbances, both of which are expected to increase as the climate changes, and on the capacity of managers and conservationists to reduce stressors caused by human activities.

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Executive Summary

Indonesia has more reef resources than any other country but its' reefs are also the world's most threatened due to the large population's high dependence on marine resources. Managers and conservationists face the challenge of preserving the world-renowned biodiversity of Indonesia's reefs while facilitating sustainable use. Threats posed by human activities are compounded by the threat of climate change, which is predicted will bring more frequent and severe bleaching events, like those observed in Indonesia in 1998/1999. Climate change greatly increases the impetus to manage reefs to support and maintain their resilience i.e. their natural capacity to resist and recover from disturbances.

To support reef resilience, managers can establish and effectively manage connected networks of MPAs that prioritise the protection of sites likely to be resilient to coral bleaching and other disturbances. Managers can also implement targeted actions to mitigate specific human stressors reducing resilience at individual sites. Taken together, identifying resilient sites and assessing human stressors has strong potential to inform management decisions that can give reefs the best chance of coping with climate change.

A formal protocol for identifying resilient reefs was first developed by the International Union for the Conservation of Nature (IUCN) in the wake of the global coral bleaching event of 1998/1999. The protocol (IUCN 2009) built on earlier work led by The Nature Conservancy (TNC), included the measurement or estimation of up to 61 'resilience factors', and produced rankings (based on high to low scores) of the relative resilience of a group of sites. Assessments were designed as 'rapid' snapshots of resilience but very few managers and conservationists have used the protocol or applied the results to management. This is because completing the surveys is resource-intensive and the protocol does not provide guidance on how to analyse the data to inform different management decisions, or how to communicate the results to managers.

In 2009, reef resilience assessments following the IUCN protocol were conducted at 121 sites in four areas spanning the archipelago of Indonesia (Aceh, Karimunjawa, Bali/Lombok, and Kofiau). In March to June 2010, an El Niño/La Niña event caused anomalously high sea temperatures throughout Southeast Asia. Reefs across Indonesia experienced bleaching including Aceh and Bali/Lombok. Bleaching was also documented at Wakatobi National Park, Southeast Sulawesi in April 2010 and resilience assessments were subsequently done in September 2010 at 23 sites. Follow up surveys to assess bleaching related mortality were done at 65 sites across Aceh, Bali/Lombok and Wakatobi in 2010 and early 2011. The severity and impact of bleaching varied among study regions and among sites within study regions. This provided an opportunity to assess if resilience scores reflected bleaching severity and impact at a large number of sites. Through this process which involved a workshop of field practicioners and experts, we also critically evaluated how resilience assessments are conducted, developed a framework for presentation and communication of resilience scores to inform management and identified next steps for refining resilience assessments.

Of the 61 resilience factors, 10 were determined to have potential to influence bleaching severity and were combined to produce a 'bleaching resistance' score for each site. However, variation in bleaching among sites within study areas was not explained by variation in bleaching resistance scores but was partly explained by the proportion of the community made up of bleaching susceptible taxa. Variation in bleaching severity and mortality among study areas was related partly to temperature stress during the bleaching event but also strongly influenced by

past variability in summer temperatures. Areas with high variability in summer temperatures (Wakatobi and Bali/Lombok) had significantly less severe bleaching and less mortality than Aceh which usually has low variability in summer temperatures. Including these factors (community composition, thermal stress and thermal history) in future resilience assessments will strengthen their capacity to accurately identify sites which are likely to be resistant to future bleaching events.

For analysis of the resilience data, we further classified resilience factors to ‘recovery’ (23) or ‘anthropogenic stress’(7). In this process we excluded 17 of the 61 resilience factors that had weak (if any) relationship with any of these categories. Resilience scores were calculated as the average of resistance or recovery scores with a higher score indicating higher resilience. Presenting the results in a color coded table for each area informs a range of management decisions that we trained conservation staff to communicate to local managers. For example, for all study areas (and the parks/locally managed areas therein) we identifed: the high resilience sites that could be protected during the next park zoning, the sites where anthropogenic stressor/s are reducing resilience, and the anthropogenic stressor reducing resilience across the largest number of sites. We describe how resilience assessment protocols could be improved based on our results. These recommendations include selecting and scaling factors based on the strength of their relationship with resilience and developing specific criteria for the scoring of factors that have to be assessed semi-quantitatively.

This is the largest-ever undertaking of a coral reef resilience assessment and the only to be paired with detailed surveys of the impacts of a severe bleaching event. As a whole, the project is a case study that can serve as an example to others as to how to operationalize reef resilience to inform management decisions. It is also our hope that the report can provoke discussion and continued advancement of this priority research area as we all work to give reefs the best chance of coping with climate change.

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Introduction

Indonesia has over 17,000 islands and is home to the world's most diverse and extensive coral reefs. These reefs are also the world's most threatened though due to Indonesia's large population and high dependence on marine resources (Mascia 2003). The challenge for managers and conservationists is to preserve the archipelago's world-renowned biodiversity while facilitating the resource use required to support reef-dependent human communities. The existing management, resource exploitation and conservation concerns in Indonesia are compounded by the threat of climate change (review in Hoegh-Guldberg et al. 2007). Amongst the most significant of the threats posed by climate change is coral bleaching (Marshall and Schuttenberg 2006). Spatially extensive or 'mass' coral bleaching events are caused when higher-than-normal sea temperatures make light toxic to the critical relationship corals have with the food-producing symbiotic algae, zooxanthellae, that give them their colour(Jones et al. 1998). Bleaching causes corals to starve and is a temporary state; if the stress abates corals can return to their normal condition but if the stress persists corals can die in great numbers. These ecologically disastrous events resulted in the loss of 16% of the world's coral reefs in 1998 (Wilkinson 2000), the last time prior to 2010 that reefs in Indonesia experienced severe bleaching.

As global temperatures increase under a regime of climate change, bleaching events are expected to increase in both frequency and severity (Hoegh-Guldberg et al. 2007). Reefs also face higher frequencies of severe storms in some areas, sea level rise, potential changes in ocean circulation, and the looming threat of ocean acidification (IPCC 2007). Climate change clearly poses challenges for managers, particularly when in combination with high anthropogenic stress on reefs as is the case in Indonesia. Managing reefs for climate change impacts also creates opportunities for innovation and collaboration (see Maynard et al. 2010). In particular, climate change increases the impetus to manage reefs to support and maintain their natural resilience (Grimsditch and Salm 2006). Coral reefs are extremely dynamic systems that are frequently disturbed (Hughes and Connell 1999). Reefs therefore depend heavily on their capacity to resist impacts and recover from disturbances – their *resilience* (Hughes et al. 2003). Resilient reefs can maintain their biodiversity and can continue to provide food and livelihoods to dependent human communities (Nystrom et al. 2000). Resilience has become a fundamental principle of reef conservation and management for these reasons (Marshall and Schuttenberg 2006).

There are a number of actions that managers can, and are, taking to support the resilience of coral reefs. Establishing effectively managed resilient networks of marine protected areas (MPAs) (Mcleod et al 2008) which incorporate risk spreading and specific sites with resilient characteristics is a key resilience strategy. Clearly, the ability to identify sites with greater relative resilience is a key management and conservation priority. Further, managers and conservationists need to determine which and to what extent stressors related to human activity are reducing resilience. This allows managers to prioritise actions such as installation of mooring buoys to reduce anchor damage or banning the spearing of herbivorous fish. Taken together, identifying resilient sites and assessing human stressors has huge potential to inform management decisions that can give reefs the best chance of coping with climate change (Maynard et al. 2010).

Several 'protocols for assessing resilience' are now in use, all of which are based on collecting data and making expert judgments of factors (e.g., coral cover, herbivorous fish abundance, substrate availability for coral recruits) known or thought to confer resilience to coral reefs. A formal protocol for assessing coral reef resilience was first developed by the International Union for Conservation of Nature (IUCN) after the mass coral bleaching event of 1998/1999, which built on earlier work led by TNC (West and Salm 2003). The IUCN protocol included the measurement or estimation of 61 'resilience factors' (Obura and Grimsditch 2009, hereafter referred to as 'IUCN 2009') and assessments were designed as 'rapid' snapshots of resilience. Values for the factors are assigned to standardized categories, the values for which can be based on local- (Maynard et al. 2010) or global-scale (IUCN 2009) variability in that factor, and averaged to produce a 'resilience score'. The main result is rankings – based on high to low scores – of the relative resilience of a group of sites. These rankings can then be used to target management and conservation effort.

Prior to this study, there has been little guidance on how to analyse the data from resilience assessments, and how to use these results to inform management decision-making. As a result, despite being critically needed, results from resilience assessments have not been used by managers because of uncertainty in their application to management decisions. In addition, until 2010 there had not been a mass bleaching event to 'test' the protocols to determine whether rankings reflected severity or impact of bleaching.

The overarching aim of the work presented here was to increase the defensibility and usefulness of coral reef resilience assessment protocols. Over the last two years in Indonesia, TNC, WCS, and Reef Check teams collected data and/or made expert judgments on the 61 resilience factors recommended in the IUCN protocol at 121 sites from three current and one proposed MPA in the archipelago (Aceh, Bali/Lombok, Karimunjawa, and Kofiau) (Figure 1). A bleaching event then occurred in 2010 at two of the four MPAs (Aceh and Bali/Lombok). Bleaching was also documented in a third area, Wakatobi, (Figure 1) and resilience scores were subsequently determined (23 sites) based on field surveys and expert judgment for this location. The 2010 bleaching event was comparable, if not more severe than the 1998/1999 bleaching event (see Figure 2).

We took advantage of this opportunity to test the capacity of the resilience assessments to predict spatial variability in the severity of bleaching responses and suggest improvements. Our goals were to:

1) Survey and describe spatial patterns of bleaching response severity during and in the 3-6 months after the bleaching event in 2010.

2) Determine the relative capacity of the resilience scores to explain the spatial variability observed in the severity of bleaching responses.

3) To the extent possible, automate the analysis and standardise a presentation format for the results that facilitates interpretation and communication of potential management decisions.

4) Explore the extent to which analysis results suggest the current marine park management plans and zoning need to be changed to restore and maintain the natural resilience of coral reef habitats.

Improving the usefulness of resilience protocols in Indonesia and the rest of the Coral Triangle is critical as designing and implementing resilient MPA networks is a key strategy to protect coral reefs from anthropogenic and climate change threats.

Figure 1. Map of sites in Indonesia where resilience and or bleaching surveys were done in 2009 – 2010

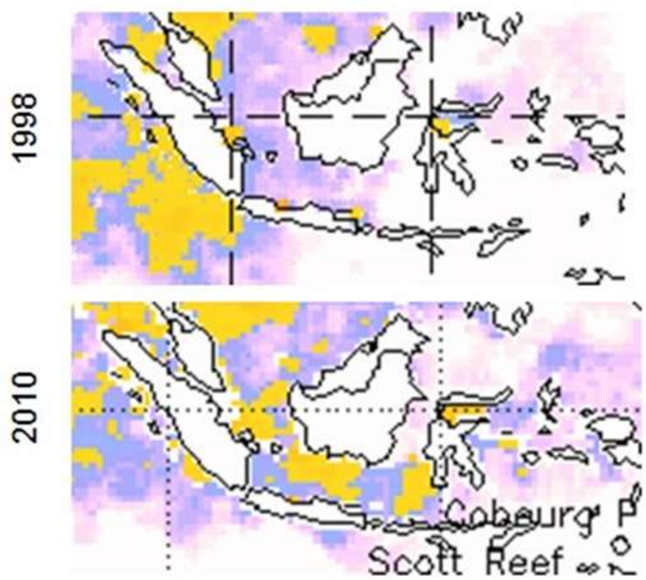

Figure 2. NOAA Coral Reef Watch Hotspots on May 26, 1998 and May 27, 2010. The 1998 bleaching event was previously considered the most severe in SE Asia. These data and the complementary Degree Heating Weeks product suggest that bleaching impacts in 2010 may have been as or even more severe than was observed in 1998. Source: http://coralreefwatch.noaa.gov/satellite/index.html.

The report is presented in two parts. Part 1 focuses on determining the drivers of the spatial variability in bleaching responses observed during the 2010 bleaching event. The focus of Part 2 is on using resilience assessments to inform management decision-making. The concluding section describes our recommendations for next steps in the areas of responding to bleaching events and developing increasingly useful methodologies for assessing coral reef resilience.

Methods

Part 1 - Bleaching patterns in 2010 and drivers of variability

Field surveys

Bleaching was first noticed at Wakatobi, SE Sulawesi in April 2010 during routine reef health monitoring surveys. Bleaching surveys were done at eight sites located throughout this study area. Subsequently, field surveys documented bleaching in Aceh in May 2010 at 13 sites and Bali/Lombok in June 2010 at 28 sites. Bleaching surveys were done along 15-25m x 1m belt transects at 10m. At one to three m depth, bleaching prevalence was recorded on the reef flat in 15 to 30 replicate 'circles' each 3.14m^2 (i.e. 1m radius) randomly chosen. All colonies along the transect were recorded and identified to genera and life form and assigned to a bleaching category of healthy, pale, bleached or recently dead.

Post-bleaching surveys were done at each study area (Aceh, July and January; Wakatobi, September and January; Bali/Lombok, January) to assess the mortality caused by bleaching. The same methods described above for the bleaching surveys were repeated during the follow-up post-bleaching surveys. To the extent possible (given weather and logistics) sites were chosen for bleaching and post-bleaching surveys that had been surveyed for bleaching in 2010 or assessed for resilience in 2009.

Data analysis

Spatial patterns in bleaching severity

For all sites in each of the three study areas affected by bleaching, three measures of the severity of bleaching were calculated: 1) the proportion of colonies **affected** by bleaching (pale and bleached), 2) the proportion of colonies **completely bleached** (bleached), and 3) the proportion of colonies **dead** due to bleaching. Bleaching severity was averaged for sites where transects were surveyed at three and 10 m. A one-way ANOVA (alpha = 0.05) was used to test for differences among study areas for all three measures of bleaching impact, for the bleaching and post-bleaching surveys.

Using resilience indicators to predict bleaching patterns

From the 61 resilience factors, we identified 16 that could have a possible link to bleaching severity or impact (Table 1). For areas where both bleaching and resilience data were available, we tested the capacity for these 16 resilience factors to predict spatial variability in bleaching impact. Factors could be tested if they met two conditions. These were:

1) on average at least 5% of the corals were affected by bleaching in the area – to ensure that there was sufficient bleaching and variation in bleaching among sites to undertake the test and,

2) at least three of the five potential scores (1, 2, 3, 4 or 5, see methods on scoring resilience factors in the next section below) were recorded and each score was recorded for at least two sites resulting in a theoretical minimum sample size of six (two sites each of three different scores).

These conditions were tested using the bleaching survey data (surveys conducted April to June 2010) and the post-bleaching survey data (surveys conducted July 2010 to January 2011). Results are only shown for the resilience factors, areas and surveys (bleaching and post-bleaching) that met both conditions (Aceh – bleaching and post-bleaching (seven factors), and Bali-Lombok – bleaching surveys only 12 factors) (Table 1). Wakatobi was not included in this analysis because only four of the eight sites where bleaching was recorded could be surveyed for resilience.

When the conditions were met, we averaged bleaching response severity and each of the three bleaching response severity measures was tested independently. For example, for 'pollution (chemical)' , we averaged the proportion of colonies affected for sites that scored 1 in each study area, and for sites that scored 2, and for sites that scored 3 (and so on). Graphs were then produced of the average bleaching response severity against the score for that factor. We tested visually whether bleaching severity declined significantly (indicated by absence of overlapping standard error bars) as scores increased (indicating higher resilience). This is what we expected if low levels of chemical pollution conferred some capacity to resist bleaching. For factors that passed this visual test we used an ANOVA (alpha = 0.05) to test for the effect of score for a factor on bleaching impact.

It is important to note that the magnitude of resilience factors can contribute positively or negatively to bleaching resistance. Therefore for all resilience factors, scores for 'negative' factors are reversed for example – a site with low pollution earns a high resilience score

Testing other indicators against spatial variation in coral bleaching

Three other indicators which have recently emerged in the scientific literature as important in bleaching but are not explicitly included in resilience assessments were tested in this study.

Coral community composition of bleaching susceptible genera

Genera identified as highly susceptible to thermal bleaching (Marshall and Baird 2000) were: *Acropora*, *Astreopora*, *Millepora*, *Montipora*, *Pocillopora*, *Seriatopora*, *Stylophora*. The proportion of the coral community made up of these susceptible genera was calculated for each site. A one-way ANOVA (alpha = 0.05) was used to test for differences among study areas and linear regressions were used to assess whether variance in bleaching response severity was explained by the proportion of the community made up by susceptible genera.

Thermal stress during bleaching

The incidence and severity of thermal stress events in each study area since 1997 was determined from sea surface temperature data available from NOAA Coral Reef Watch (CRW) 50-km dataset[1] since 2000 (Liu et al. 2003) at bi-weekly intervals and augmented with a retrospective 50-km dataset (Eakin et al. 2009) derived from Pathfinder 4km data (see below; Kilpatrick et al. 2001) for the period 1997-2000. 50km is not a sufficient resolution to test for differences in thermal stress among sites within our study areas (i.e., sites are generally too close together) so we used data from the pixel closest to the central-most location in each of the five study areas.

[1] http://coralreefwatch.noaa.gov

Degree heating weeks' (DHWs)[2] were calculated for the period 1997-2010 using the standard NOAA CRW methodology as a measure of the accumulation of thermal stress through time[3]. DHWs start accumulating when temperatures exceed 1°C above the long-term maximum monthly mean (Liu et al. 2003). DHWs were plotted for each study area since 1997.

Table 1: Subset of the resilience factors from the IUCN (2009) protocol that have known or potential links to bleaching/bleaching resistance. Whether the factor contributes (positive, +) or reduces (negative, -) bleaching resistance is denoted by the sign following the factor. * = could be positive or negative but is considered and assessed here at levels that could only reduce rather than confer bleaching resistance. ** = have tenuous links at best to bleaching resistance or could have either a positive or negative effect on resistance and are only explored here in the spirit of testing *all* of the factors with possible links to bleaching resistance.

Bleaching resistance factor	**Relationship with bleaching**	**Aceh (bleaching and post-bleaching)**	**Bali (bleaching)**
Turbidity/ sedimentation	+/-*	X	X
Environmental quality	+	X	X
Pollution (chemical)	-	X	
Wave energy / exposure	+		X
Deep water (30-50m)	+		X
Canopy corals	+		X
Ponding/ pooling	-		X
Temperature variability	+		X
Nutrient input	+/-*		X
Exposed low tide	-		
Largest corals	+		
Physical shading	+		
Fishing pressure**	-	X	X
Dominant size class**	-	X	X
Herbivores**	+	X	X
Pollution (solid)**	-	X	X

[2] A DHW is equivalent to one week of sea surface temperature 1 deg. C above the expected summertime maximum. For example, two DHWs indicate one week of 2 deg C above the expected summertime maximum.

[3] http://coralreefwatch.noaa.gov/satellite/methodology/methodology.html

Spatial patterns in thermal history

We calculated the variability of sea surface temperatures (standard deviation around the mean) during the hottest quarter of the year – the three hottest months on average. NOAA's 4-km Pathfinder dataset (1985-2009)[4] was used to determine the average monthly temperature for each month at all of the sites surveyed for bleaching. A one-way ANOVA (alpha = 0.05) was used to test whether differences among areas in the average temperature variability during the hottest months are significant.

Part 2 – Resilience assessments and management decision-making

Field surveys

Resilience assessments were completed at sites across five study areas in Indonesia (Aceh, Karimunjawa, Bali/Lombok, Wakatobi and Kofiau) in 2009-2010 following the method presented within IUCN (2009, Table 2, Appendix B). In short, 61 factors thought to be related to coral reef resilience were assessed at each site either through quantitative measurement, or expert judgment. All factors were converted to a Likert scale by assigning a score of 1 to 5 for each factor for each site. Note that some resilience scores for sites in Karimunjawa and Wakatobi were determined largely from some limited quantitative measures and estimation using expert judgment or other data sources. Factors assessed semi-quantitatively using expert judgment were estimated by one of the authors (Rizya Ardiwijawa) who was involved in the resilience assessments undertaken in all other study areas.

Workshop – Bali, April 2011

A workshop was held in Sanur, Bali from April 18-21, 2011 to review the field methods used (reviewed above) and to discuss ways to analyse the data to inform management decision-making in each of the five study areas. The workshop participants were a unique combination of research scientists, conservation leaders, science managers, monitoring specialists and field staff tasked with reef health monitoring and resilience assessments in Indonesia (see list of attendees in Appendix A). Specifically, the workshop had these four goals:

1. Determine which, if any, of the resilience factors should be excluded from the analysis due to weak (if any) relationships with bleaching resistance and recovery (from any disturbance).
2. Optimise the presentation of resilience analysis results to inform a range of management decisions (i.e., zoning, and targeted actions).

Determine the optimal timing and frequency of resilience assessments and discuss current and future training needs and logistics issues. Practice communicating the results of the analyses to managers.

[4] http://www.nodc.noaa.gov/sog/pathfinder4km/

Table 2: Survey dates and methods used for each of the five case study areas.

Study area	**Aceh**	**Karimunjawa**	**Bali/Lombok**	**Wakatobi**	**Kofiau**
Survey month	March 2009	April 2009	January 2009	September 2010	April 2009
Number sites (n)	19	43	28	23	42
Methods					
1. Benthic cover	PIT 2009	PIT 2009	√	PIT 2010	√
2. Coral community composition	√	×	√	×	√
3. Coral size classes and population structure	√	√	√	×	√
4. Coral condition and threats	√	×	√	√	√
5. Fish community structure and herbivory	√	√	√	×	√
6. Site resilience factors	√	√	√	√	√

√ = using IUCN (2009) methods, × = data not collected but estimated

Data analysis

Resilience scores were calculated using two methods. Firstly, resilience scores were calculated using the methodology described in IUCN (2009) where each of the 61 factors is assigned to one of 14 factor groups (Table 3). An average for each factor group is calculated and then an average of these 14 scores produces a single resilience score for each site.

Secondly, we developed a new framework for analysis of resilience assessment data. This involved identifying factors which workshop participants considered had only a weak or no relationship with bleaching resistance or recovery. A total of 19 factors were identified (Table 3) and excluded from the analysis. Bleaching was excluded here because we were testing for resilience to the spatially extensive severe bleaching events caused by thermal stress. Resilience surveys were not undertaken during the summer season or during thermal anomalies so the presence or absence of bleaching would not indicate resistance to thermal stress. Survival of past bleaching was also excluded because this information was available for very few of the study sites in this analysis.

Then, we categorized remaining factors into three categories relating to 'bleaching resistance', 'recovery', or 'management' (see Table 4). Score for bleaching resistance, recovery and management were calculated for each site as an average of individual factors for each category. (Table 4). An overall 'resilience score' was produced by averaging scores for bleaching resistance as well as the factors related to recovery. Throughout the report 'resilience score' now refers to scores from this calculation not from calucualtions using IUCN 2009. Sites were ranked from highest to lowest resilience score for each of the five study areas.

Scores for all categories (resilience, resistance, recovery and management) were classified on a relative scale of low, medium and high for each of the study areas on the basis of the range of scores for each study area. This was done by subtracting the lowest score from the highest score for each study area. The total range was then divided by three to identify the ranges for low, medium, and high. For example, if 5 is the highest score, and 2 the lowest, the range is 3, and 3 divided by 3 (for 3 bins) equals 1. Therefore sites with scores ranging from 2 – 2.99 would be assigned to low, 3-3.99 = medium, and 4-5 = high. Throughout the report, these three classifications are colour-coded; low – red, medium – yellow, high – green. We used an unpaired *t*-test to determine whether the average score for factors relating to bleaching resistance was significantly different than the average score for factors relating to recovery (alpha - 0.05). The resilience scores produced by this method and that of IUCN 2009 (described above) are compared for each of the five study areas.

Table 3: Resilience factors, by IUCN 2009 factor groupings. Factors in bold were excluded from the final analysis due to having a weak (if any) relationship with bleaching resistance or recovery.

Factor group (IUCN 2009)	Resilience factor	Factor group (IUCN 2009)	Resilience factor
Coral	CCA	Connectivity	Currents
	Dominant size class		Dispersal barrier
	Fragmentation		Distant seeding (100)
	Hard Coral		Local seeding (10 km)
	Largest corals (3)		Self-seeding
	Recruitment	Algae	Fleshy Algae
	Soft Coral		Turf Algae
Interactions	**Branching residents**	Negative Association	**Bioeroders (external)**
	Obligate feeders		**Bioeroders (internal)**
Herbivores	Excavators		**Competitors**
	Grazers/ Browzers		**Corallivores (negative)**
	Herbivores	Impacts	**Bleaching**
	Scrapers		**Coral disease**
Piscivores	Piscivores		**Mortality-old**
Cooling	**Currents**		**Mortality-recent**
	Deep water (30-50m)		**Recovery-old**
	Depth of reef base (m)	Anthro stress	Destructive fishing
	Temperature (^{o}C)		Dispersal barrier
	Wave energy/ exposure		Fishing pressure
Screening	Canopy corals		Nutrient input
	Compass direction/ aspect		Physical damage
	Depth (m)		Pollution (chemical)
	Physical shading		Pollution (solid)
	Slope (degrees)	Management	Biodiversity
	Visibility (m)		Environmental quality
Extremes	Exposed low tide		Resources
	Ponding/pooling		
	Survival of past bleaching		
	Temperature variability		
Substrate	Rubble		
	Sediment layer		
	Sediment texture		
	Topographic complexity - macro		
	Topographic complexity - micro		

Table 4: Resilience factors classified as relating to bleaching resistance, recovery (any disturbance), and to either resistance and recovery but are also amenable to management (classified under 'management'). Factors in bold are assigned to more than one classification.

Resistance	Recovery	Management
Turbidity/ sedimentation	Fleshy algae	Desructive fishing
Environmental quality	Turf algae	Fishing pressure
Pollution (chemical)	Dominant size class (coral)	Nutrient input
Wave energy / exposure	Fragmentation	Physical damage
Deep water (30-50m)	Hard coral cover	**Pollution (chemical)**
Canopy corals	**Largest corals**	Pollution (solid)
Ponding/ pooling	Recruitment	**Turbidity / sedimentation**
Temperature variability	Soft coral cover	Herbivores
Nutrient input	Crustose coraline algae cover	Excavators
Exposed low tide	Rubble	Grazers / Browsers
Largest corals	Sediment layer	Scrapers
Physical shading	Sediment texture	Biodiversity
	Topographic complexity - macro	**Environmental quality**
	Topographic complexity - micro	Resources
	Currents	Piscivores
	Dispersal barrier (connectivity)	Dispersal barrier (anthropogenic stress)
	Distant seeding (>100 km)	
	Local seeding (>10 km)	
	Self-seeding	

Applying results to management

The results are presented to inform three different types of potential management decisions:

1) Identification of sites that have high or medium resilience scores and are currently not included in a marine protected area (MPA) or are in a use zone within an MPA.
2) Identification of strategies that could be implemented to (further) reduce anthropogenic stress at sites with high or medium resilience but low scores for management.
3) Actions that can be taken at the whole-of-park scale to increase the resilience of most sites in the area.

Sites have been identified for each study area that meet the criteria shown in 1 and 2, and the actions that would benefit the resilience of the highest number of survey sites have been identified for each study area. We also use an unpaired *t*-test (alpha – 0.05) to test whether the average score for sites currently designated no take is significantly different (higher or lower) than sites currently designated as use zones. Use zones could be 'utilization' or 'open access' and either could have gear and/or species restrictions on fishing in place.

Results and Discussion

Part 1 - Bleaching patterns in 2010 and drivers of variability

Spatial Patterns in Bleaching Severity

Bleaching was observed on many reefs throughout Indonesia in 2010 although the indicence and severity of bleaching was highly variable geographically (Chou 2011). Of the five areas studied here, Aceh, Bali and Wakatobi experienced severe thermal anomalies in 2010 (see Figure 10) and surveys documented the bleaching incidence and post-bleaching mortality up to one year post-bleaching event. Results from bleaching (April-June 2010) and post-bleaching (July, 2010 to January, 2011) surveys are presented separately below.

Bleaching (April to June 2011)

Sites in Aceh bleached more severely than sites in the other two study areas, and Wakatobi bleached more severely than Bali (Figure 3). Approximately 90% of Aceh's coral colonies were affected by bleaching with ~70% completely bleached (Figure 3). Bleaching impacts on coral reefs at Wakatobi were less severe than those at Aceh – approximately 60% of colonies were affected and 35% completely bleached. Bali experienced the least severe impacts, with approximately 20% of colonies affected and 10% completely bleached. At the time of these surveys, mortality due to bleaching was minor (less than 5% at all sites, Figure 4). Differences between study areas for all three bleaching severity classifications are significant (affected F_2 = 118.6, $p<0.001$, completely bleached F_2 = 77.89, $p<0.001$, and dead F_2 = 4.14, $p<0.05$).

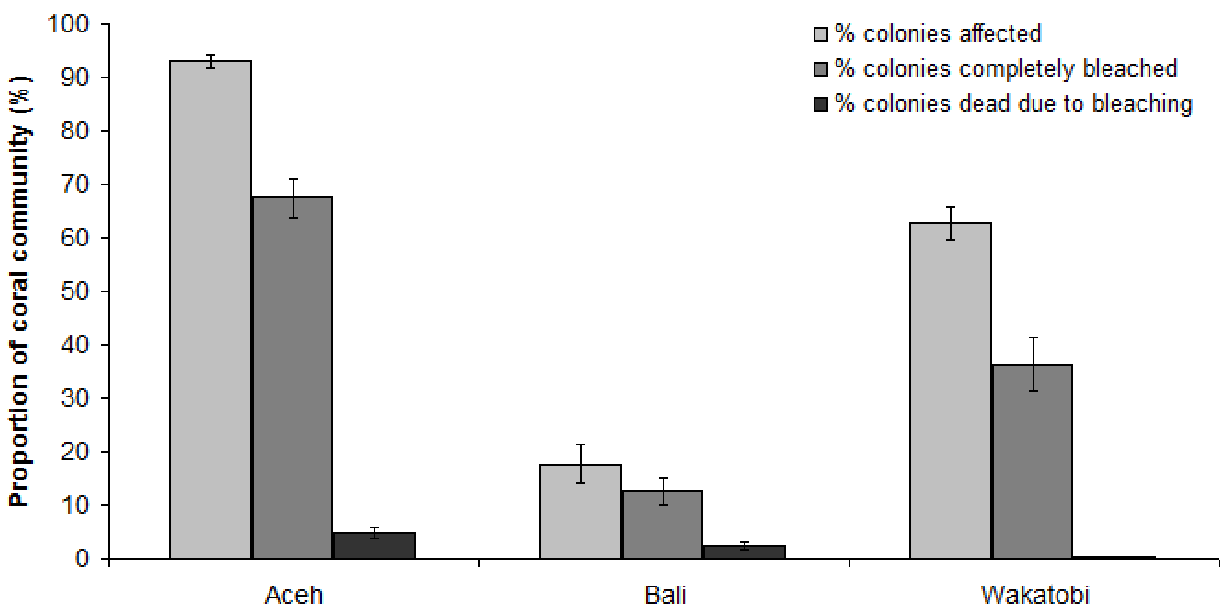

Figure 3. The proportion of the coral communities in each study area affected by bleaching, completely bleached, and dead due to bleaching during bleaching surveys undertaken between April and June 2010. Differences between areas for each of the three bleaching severity classifications are significant (see text

Post-bleaching (July, 2010 to January, 2011)

Post-bleaching surveys were completed between one and nine months after the bleaching event in order to document long-term impacts.

In Aceh, approximately 85% of corals were still affected by bleaching In July 2010 with 33% completely bleached and more than 40% of corals had died due to bleaching stress (Figure 4). The mortality observed in July 2010 is highly likely to be an underestimate of the total mortality caused by bleaching. This is because it is likely that a proportion of the completely bleached colonies are likely to have died in the months that followed the surveys.

In Bali and Wakatobi there were only a few corals still affected by bleaching (<3%) when surveys were done in January, 2011 and September 2010, respectively (Figure 4). Bleaching induced mortality was estimated to be low at both sites but may have been underestimated (particularly in Bali) since post-bleaching surveys were conducted four to eight months after the peak of thermal stress (i.e., dead corals may have become overgrown by algae and not appear recently killed). Recently killed corals were recorded but corals killed in the month that followed the bleaching could have been hard to distinguish from longer-dead corals. Differences between study areas for all three bleaching severity classifications are significant (affected $F_2 = 1350.85$, $p<0.001$, completely bleached $F_2 = 1591.87$, $p<0.001$, and dead $F_2 = 143.94$, $p<0.001$).

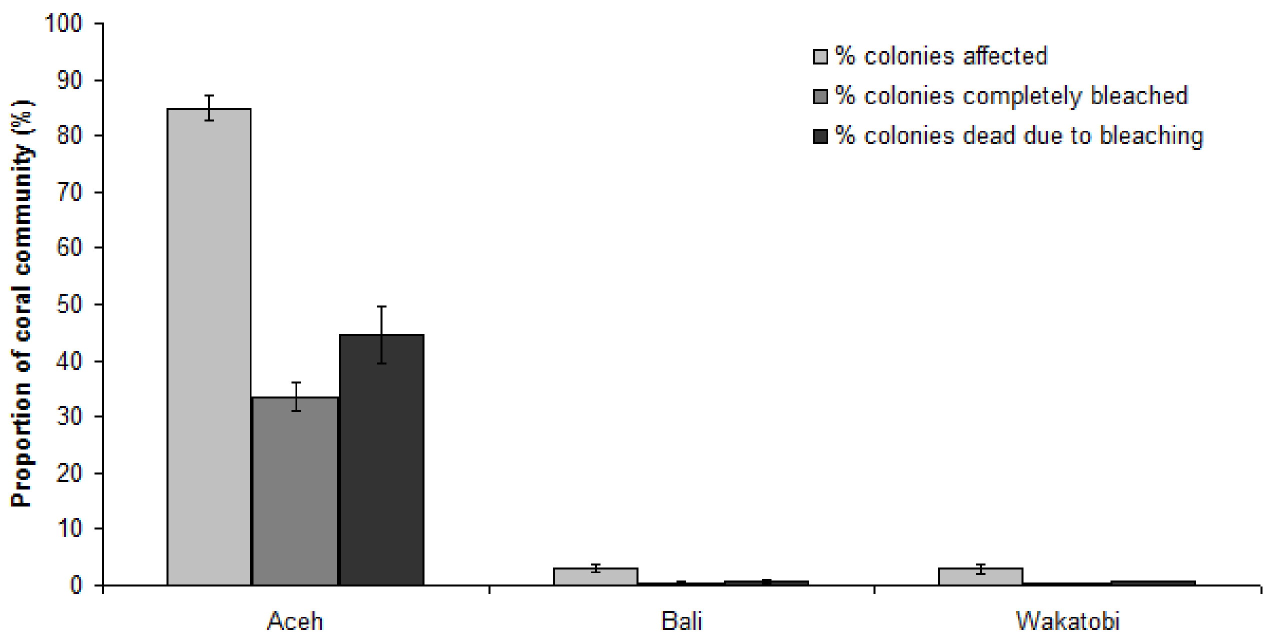

Figure 4. The proportion of the coral communities in each study area affected by bleaching, completely bleached, and dead due to bleaching during post-bleaching surveys undertaken between July and January 2011. Differences between study areas for each of the three bleaching severity classifications are significant (see text for details).

Causes of differences in bleaching response among and within study areas

Differences in bleaching response severity between study areas could be explained by differences in: the timing of the bleaching and post-bleaching surveys with respect to the peaks in thermal stress, the severity of thermal stress during the event, spatial variability in thermal history, and/or the relative capacity of sites in each area to resist bleaching, all of which are explored and discussed in the upcoming sections.

Using resilience indicators to predict bleaching patterns

We tested whether bleaching resistance indicators could be used to predict bleaching patterns during and after the bleaching event in Aceh, and during the bleaching event in Bali/Lombok. As per methods, we only tested factors and sites which met both conditions for analysis i.e. at least 5% of the corals were affected by bleaching in the area and each of at least three resilience scores were recorded at multiple sites at the study area (for further detail see Methods and Appendix C).

In Aceh, there was sufficient variation in the scores for seven of the 16 factors. Bleaching severity (% of colonies affected by bleaching) in June, 2011 declines as the scores increase for four of the seven factors – pollution (chemical), pollution (solid), environmental quality, and dominant size class (denoted with an asterisk in Figure 5) which indicates bleaching resistance is higher at sites with high scores for these factors. However this relationship is only significant for one factor – environmental quality (see Figure 5). This result indicates that environmental quality – an assessment of the general quality of the environment for coral growth – may explain some of the variation in bleaching response severity observed during the bleaching surveys in Aceh. Importantly though, there is only a small (7.1%) difference in bleaching serverity between sites that scored 4 (87.1 ± 2.31) rather than a score of 2 (94.2 ± 3.40) This suggests that there may be a high chance of a Type II error in this analysis perhaps due to low sample size.

We also tested whether fewer colonies died as a result of bleaching in Aceh at sites that received high scores for these same seven factors. We found that bleaching impacts were not less severe at sites with high scores for any of these factors.

For Bali/Lombok, we were able to test the relationship between bleaching severity and resilience score for 12 bleaching resistance factors during bleaching surveys in May 2010. However none showed any relationship between bleaching and resilience (see Figure 7).

For Wakatobi, none of the factors met the conditions for analysis of this relationship so the resilience factors could not be tested against bleaching impacts.

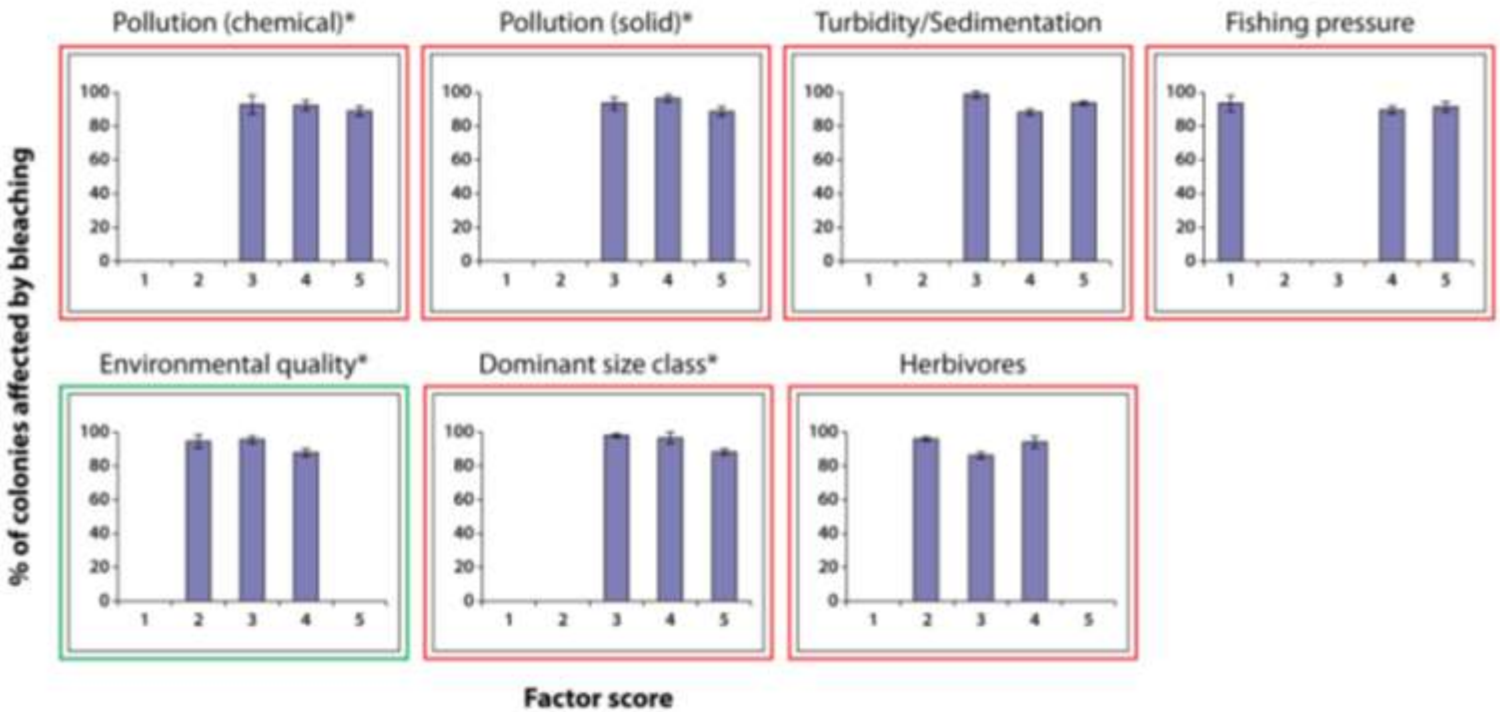

Figure 5: Relationship between scores for seven factors relating to bleaching resistance and the % of colonies affected by bleaching in Aceh in June of 2010. Factors with the relationship with the % of colonies affected by bleaching that we tested for (i.e., bleaching severity declines as scores increase) have an asterisk. Only the factor “Environmental quality” was shown to be a significant ($p<0.05$) predictor of bleaching severity (in green box; the non-significant results are in red boxes).

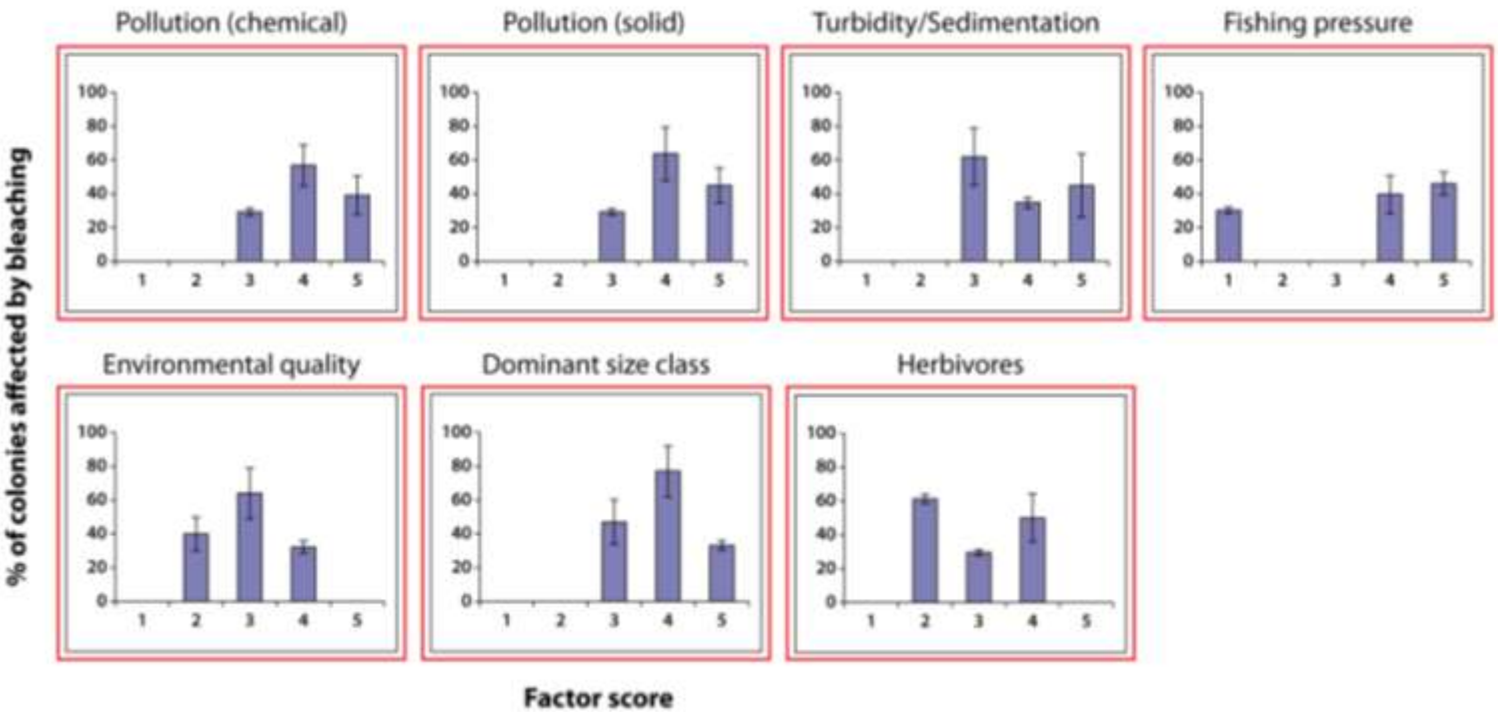

Figure 6. Relationship between scores for seven factors relating to bleaching resistance and the % of colonies dead due to bleaching in Aceh in July of 2010. None of these factors confirm that bleaching severity declines as scores increase.

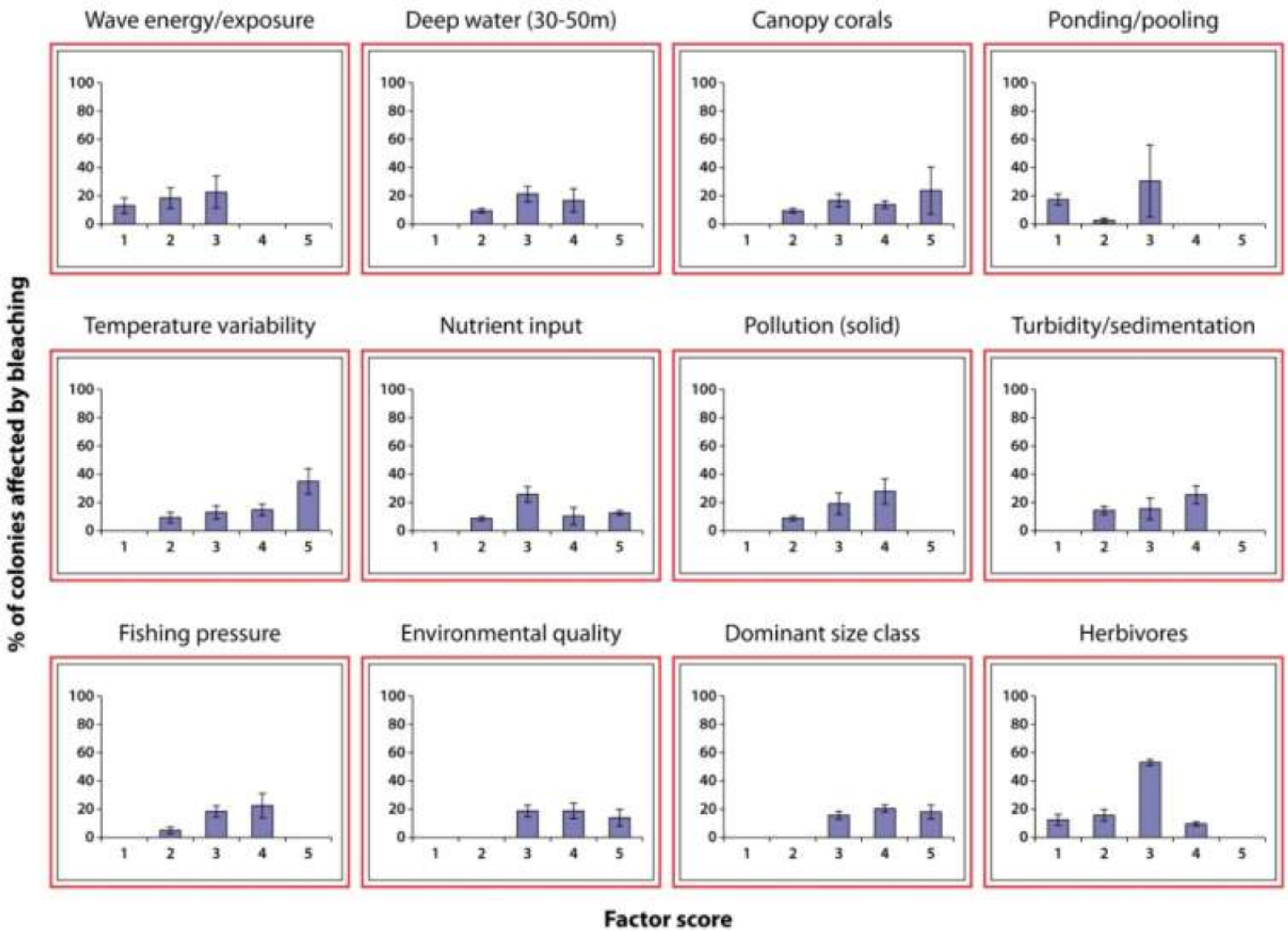

Figure 7. Relationship between scores for 12 factors relating to bleaching resistance and the % of colonies affected by bleaching in Bali/Lombok in May of 2010. None of these factors show that bleaching severity declines as scores increase.

Coral community composition

Intra-study area differences in bleaching severity in our study areas are driven in part by the proportion of the coral community at each site made up by susceptible taxa. The proportion of the community made up by bleaching-susceptible taxa explains 22% of the variation in bleaching severity in Aceh, 26% in Bali and 43% in Wakatobi (Figure 8). Further, in all three areas, the site with the highest proportion of bleaching-susceptible taxa was amongst the three most severely bleached sites in the area. For example, in Aceh, 99% of the corals were affected by bleaching at a site with 74% of the community made up by susceptible taxa. Local-scale variability in thermal stress during the event probably explains much of the rest of the intra-area (within the MPA) variation in bleaching severity (i.e., sites with high proportions of susceptible taxa may not have bleached because thermal stress was low) but remotely sensed temperature data were not available at less than 50km resolution at the time of reporting.

Differences in bleaching severity *between* the three areas cannot be explained by differences in the relative proportion of taxa known to be susceptible to bleaching. In all three areas the average proportion of the coral community made up by bleaching-susceptible taxa is ~35% (see Figure 9), and differences are not significant ($F_2 = 0.1256$, $p = 0.88$).

The 'proportion of the community made up by susceptible taxa' is known to be a major driver of bleaching patterns and patterns of susceptibility among taxa are highly predictable (Marshall and Baird, 2000). Yet, this factor is not explicitly included in the list of 61 factors recommended in the IUCN resilience assessment protocol (2009). The results presented here suggest this factor should be included in future resilience assessment protocols and will need to take into consideration that the hierarchy of bleaching susceptibility among taxa (as in Marshall and Baird, 2000) is unlikely to hold true for all locations and may change through time.

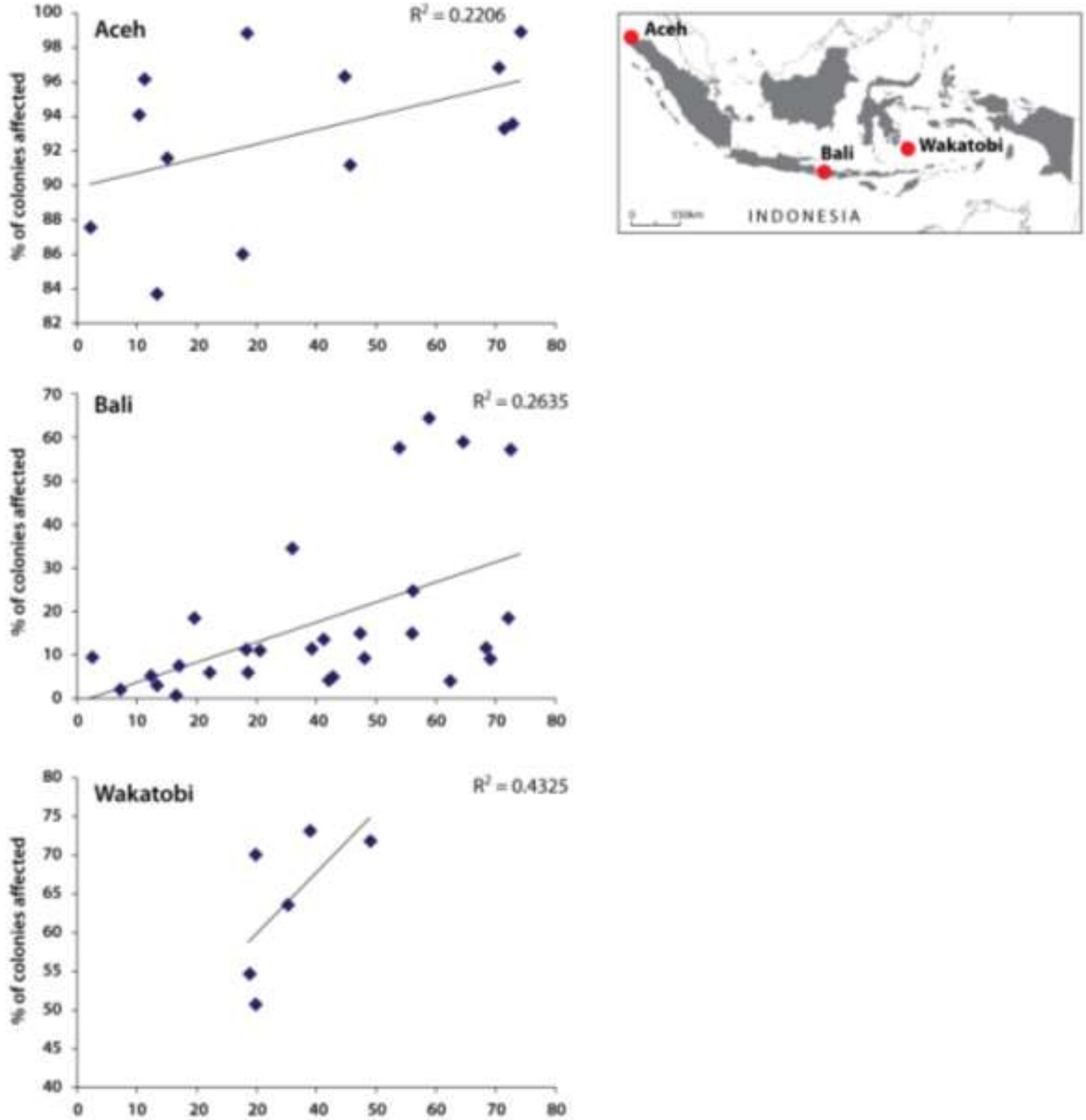

Figure 8. The relationships between the proportion of the community made up by bleaching-susceptible taxa and the % of colonies affected (showing any signs of bleaching, event paling) by bleaching at the three study areas in 2010.

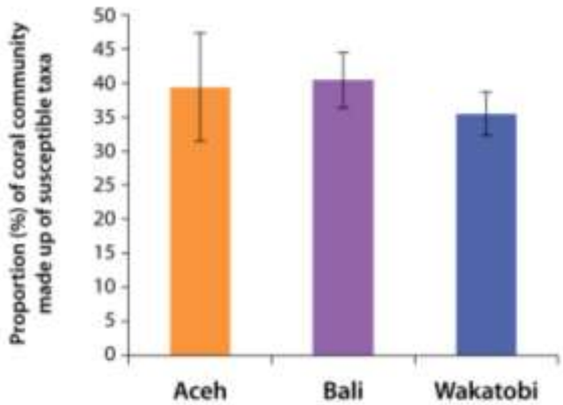

Figure 9. The average proportion of the coral communities made up by bleaching-susceptible taxa (see methods for more detail) in the three study areas where bleaching was documented.

Timing of surveys

In this study, mortality caused by bleaching may have been underestimated in Bali and Wakatobi due to follow-up surveys being conducted late, and underestimated in Aceh due to follow-up surveys being conducted early. Because bleaching surveys were undertaken during near optimal times in all three areas and the reefs in Aceh were bleached much more severely than reefs in Wakatobi or Bali during those surveys, it is highly unlikely that survey timing explains much of the *difference* in mortality.

Due to the physiology of bleaching in corals there is a lag between the thermal stress reaching levels conducive to bleaching and the corals being visibly bleached (Maynard et al. 2009). This lag time can be days, depending on the rates of thermal stress accumulation at a site, but is usually 1-2 weeks. For this reason surveys conducted too early or too late can underestimate the severity of bleaching responses. If surveys are too early, many corals will have yet to bleach. If surveys are too late, corals that only slightly bleached may have returned to their normal colouration. The same is true for follow-up surveys used to estimate the mortality caused by bleaching. If surveys are conducted too early corals may be bleached but have yet to die. If surveys are too late recently dead corals can be difficult to distinguish from long-dead corals due to rapid rates of algal colonisation.

Implementing timely surveys in response to bleaching events poses logistical challenges and can be costly. Having bleaching response plans in place in Indonesia can help ensure contingency funds are included in budgets and released to mobilize response teams when bleaching risk is high.

Spatial patterns in temperture stress during bleaching and ’thermal history’

The 2010 bleaching event was caused by anomalously high sea surface temperatures associated with a La Niña event. At Aceh, Bali and Wakatobi, the temperature stress in 2010 as measured by DHWs was unprecedented over the last 12 years, and far greater than the stress levels seen in 1998 when the last region-wide bleaching event occurred (Figure 10). In contrast, Kofiau and Karimunjawa were not exposed to stressful temperatures for a sufficient duration to cause bleaching in 2010 (Figure 10). Coral reefs in the Aceh area experienced 4.65 DHWs. Coral reefs in the Bali and Wakatobi area experienced more severe thermal stress than the reefs in Aceh with a total of 6.5 DHWs each (Figure 10).

The fact that bleaching was more severe in Aceh than in Bali or Wakatobi despite lower levels of temperature stress is surprising. We tested whether corals in Aceh could be relatively less bleaching-resistant due to low variability in temperatures during the hottest 3-month period (April-June in all our study areas, based on monthly average temperatures). Researchers have shown that corals in east Africa (McClanahan et al. 2007) and SE Asia, including Indonesia (Guest et al. in review), bleach more severely at locations where the variability in temperatures during the hottest months is lowest.

We found temperature variability (standard deviation) to be lowest in Aceh (0.7) where bleaching was most severe and highest in Wakatobi (0.94, see Figure 11). Differences between study areas in temperature variability are significant ($F_2 = 96.47$, $p<0.001$). We suggest that corals in Bali and Wakatobi could have acclimated/adapted to the relatively large swings in temperatures common at sites in these areas during the hottest months. As a result, corals at these locations could be more bleaching resistant, causing them to bleach less severely than corals in Aceh despite experiencing higher levels of temperature stress. This result could explain the large differences in bleaching severity between Aceh and the other two areas; Wakatobi and Bali, but not between Wakatobi and Bali where differences in temperature variability are slight (0.84, 0.90 respectively). Differences in bleaching response severity between these two areas are probably driven by local-scale differences in the thermal stress experienced in 2010. More sites were surveyed for bleaching in Bali than in Wakatobi over a larger spatial area, highlighting the need to review high-resolution (4-km) temperature data for the event when the data become available in early 2012.

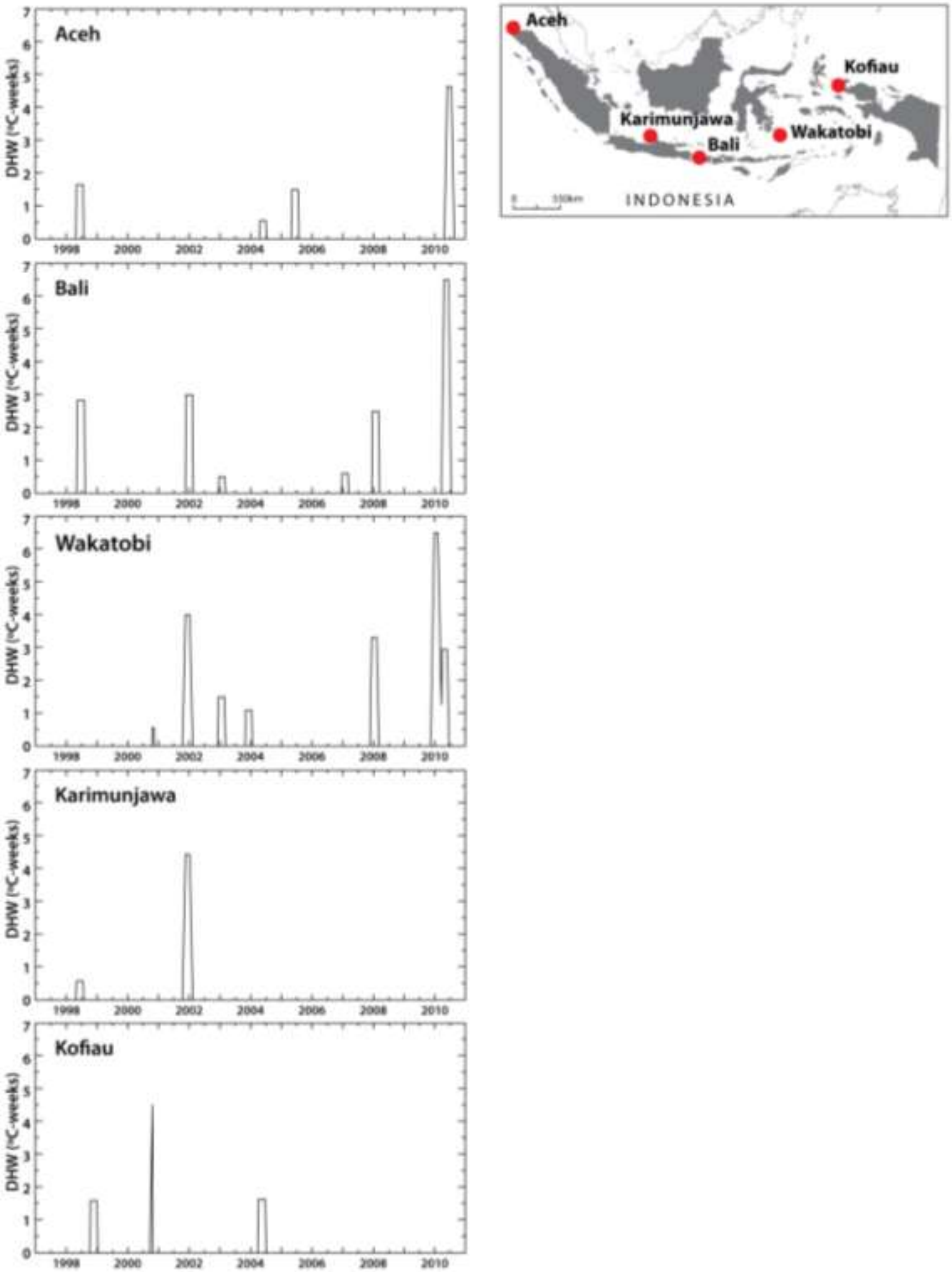

Figure 10. Annual degree heating weeks (DHWs) for the last 12 years for the study areas from the near real-time and retrospective NOAA Coral Reef Watch datasets (50-km resolution). Data shown are for the pixel nearest to the central-most study site in each of the study areas.

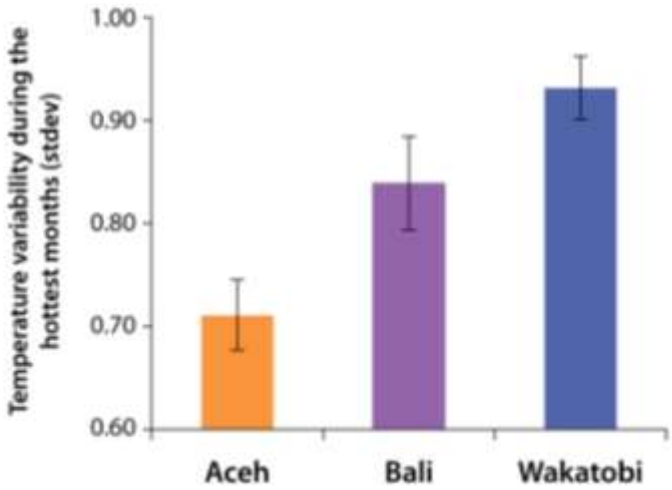

Figure 11. Temperature variability (standarad deviation - stdev) during the hottest months at each of the three study areas. Differences are significant between all three areas, but not between Bali and Wakatobi.

Factors which explained variation in bleaching severity

This study has shown that differences in bleaching response between sites within a study area and between regions were not well explained by variation in resilience indicators which was unexpected. However, three additional factors were tested (proportion of the coral community made up of bleaching susceptible genera, thermal stress during bleaching and thermal history) and found to better explain small and large scale variation. The capacity of the resilience indicators to predict variability in bleaching responses could be low for one or a combination of at least five different reasons. These reasons are described below and a description is provided of how these issues were or could be addressed is provided.

(a) Thermal history i.e temperature variation during the hottest months was found to be a significant predictor of inter-area (among the study areas) differences in bleaching response severity. While temperature variation is included as a factor in the IUCN (2009), it is assessed subjectively and therefore the capacity to accurately assess local-scale variation in temperature variability is limited.

We calculated historical variability in temperatures during the summer months using remotely sensed SST data and variability and found there was a significant relationship with bleaching severity. This indicates the importance of using temperature variation as a resilience factor but ensuring it is calculated accurately.

(b) We found that the proportion of the community made up by bleaching-susceptible taxa and explains >20% of the differences in bleaching response severity among study areas. The resilience assessment protocol (IUCN 2009) excludes the 'proportion of the community made up by bleaching-susceptible taxa'.

(c) Bleaching severity may have been underestimated in Bali and Wakatobi and mortality may have been underestimated in Aceh as a result of survey timing. This may have affected the results of tests to assess the relationship between bleaching impacts and resilience factor scores. We recommend developing bleaching response plans and securing contingency funds so that surveys for bleaching impacts can be conducted during, three and six months after the peak of thermal stress.

(d) Local-scale variability in temperature stress during the event probably has a greater capacity to predict bleaching patterns than any of the factors assessed in the protocol that relate to bleaching resistance. Until higher-resolution thermal stress monitoring tools are made available by NOAA Coral Reef Watch (currently operational at 50km-resolution), we have to perform these analyses post-event (when gap-filled, quality-controled 4km data becomes available via Pathfinder). We will perform such an analysis in the coming year to determine the extent of the local-scale variability in bleaching severity that can be explained by temperature stress

(e) Many of the factors in the IUCN (2009) protocol are assessed relatively subjectively or semi-quantitiatively which can result in differences between assessors. More specific criteria need to be established to provide guidance on semi-quantitative assessment of the factors that require such methods. We standardised the scoring system used here but had to convert data to perform the analysis, which is likely to have introduced some subjectivity. The next step is to develop standard criteria for refined global and regional-scale resilience assessment protocols (see conclusion).

In summary, the issues identified have led us to the listed solutions. In combination, these solutions will help us to increase the capacity of resilience assessments to predict variability in bleaching resistance during future thermal stress events.

Part 2 – Using resilience assessments to inform management decision-making

Aceh

Area Description

Aceh is located on the northwestern tip of Sumatra, western Indonesia and includes three large islands - Weh, Beras and Nasi Islands. The islands and coral reefs of this area are diverse and also important to support local fisheries. The 40 000 residents of this area have a high dependency on the marine resources with most people deriving food and income from artisinal fishing. This area was hit by a major tsunami in December 2004, but reefs have recovered perhaps also due to a subsequent reduction in bomb fishing. Marine Protected Areas in this area include the Weh Marine Tourism Park established in 1982 by the district government, and a community managed MPA in east Weh Island. Fishing and other extractive activities are managed in the MPAs, which together encompass 58 000 ha. The remaining areas are open to general use.

Resilience, Bleaching Resistance and Recovery

The resilience scores for Aceh range from a low of 2.59 (Leun Balee 1) to a high of 3.97 (Ba Kopra; Table 5). The range of scores (1.38) was divided into three bins to categorize the resilience of each site relative to the other 19 sites surveyed in the area: low (2.59 – 3.05), medium (3.05 – 3.51), and high (3.51 – 3.97; shown as red, yellow and green, respectively in Table 5). The range of scores (from highest to lowest resilience score) is large relative to other MPAs in the study, indicating substantial differences between the capacity of sites in the area to resist bleaching and recover from disturbances.

Five sites were classified as having low relative resilience, nine sites have medium resilience, and five sites have high resilience. In this area, the resilience scores calculated here as the average of the scores for factors relating to bleaching resistance and recovery (Table 5) are similar to the scores calculated when all of the resilience factors recommended by IUCN (2009) are included. With either methodology – that used here or presented in IUCN (2009) – the same five sites have the highest resilience scores and the same five sites have the lowest resilience scores though in both cases the site ranking order changes (Table 5). This result was unique to this area as usually the two methodologies produced very different results.

The average score for factors relating to recovery (3.54 $\pm$ 0.09) is greater ($t_{36} = 4.726$, $p<0.001$) than the average score for factors relating to bleaching resistance (2.91 $\pm$ 0.09). Pasi Janeng 2, classified as having low relative resilience, is the only site in which the average score for factors relating to bleaching resistance was greater (only by 0.07) than the average score for factors relating to recovery.

Bleaching in 2010

Sites within this area experienced bleaching in 2010 following a severe thermal anomaly. Only eight sites were surveyed for bleaching *and* assessed for resilience. There is no relationship between resistance score ($R^2 = 0.01$) and the % of colonies affected by bleaching (see Figure 12). This suggests that the *current* capacity of the resistance score to predict bleaching patterns is either limited generally or limited in this area, which could be due to one or a combination of the issues described at (c), (d), and (e) on page 18.

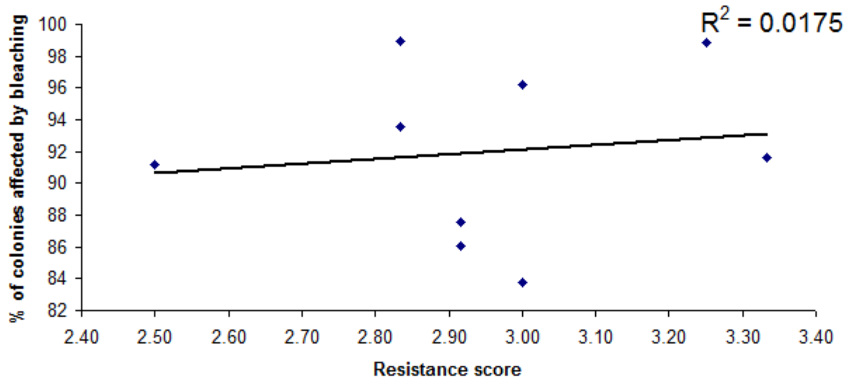

Figure 12. The relationship between resistance score and the % of colonies affected by bleaching in Aceh in June of 2010 is unclear and not that expected given bleaching severity increases (rather than decreases) slightly as resistance score increases.

Management

The average resilience score for sites currently designated no take (3.48 + 0.07) is greater (t_{17} = 2.501, $p<0.05$) than sites designated for use (3.09 + 0.12) (Figure 13). Four of the five sites with the highest resilience scores are protected as no-take areas (see Table 5). The five sites with the lowest resilience scores are all sites designated as use areas within the community-managed or government MPAs. Only one site – Jaboi - is classified as having high or medium resilience (medium in this case) and a low score for factors managers can influence indicating that most high or medium resilience sites are within no-take areas. These results indicate that, to an extent, the current marine park zoning scheme already takes resilience into consideration. Specific recommendations to further increase the resilience of this group of sites through revisions to the zoning are offered in the section below.

For the 16 factors that managers can influence (see Table 4), the four factors with the lowest average scores are: 'Environmental Quality' (2.37 ± 0.26), 'Piscivores' (2.32 ± 0.20), 'Excavators' (1.63 ± 0.24) and 'Scrapers' (1.32 ± 0.15) (Table 6). Therefore, addressing these four would increase resilience at most of the study sites.

Table 5: Average scores for resilience in Aceh (all factors relating to bleaching resistance and recovery), and these factor categories: bleaching resistance, recovery, and management. Sites are ranked from highest (1) to lowest resilience score (19). Colour bins shown are low, medium, and high relative classifications by column (see methods for more detail). The ranks and resilience scores (*) shown with asterisks are the analysis results found when all of the resilience factors recommended by IUCN (2009) are included. Marine park zones (*) in Aceh vary but are broadly classified here as 'No Take' and 'Use'; some regulations (i.e., quotas, gear or species restrictions) may exist in areas designated for use.

Site name	Marine Park Zoning	Rank	Resilience	Bleaching Resistance	Recovery	Management	Rank*	Resilience*
Ba Kopra	Use	1	3.97	3.50	4.26	2.81	4	3.20
Canyon	No Take	2	3.75	3.50	3.89	3.17	1	3.36
Ujung Seuke	No Take	3	3.69	3.33	3.95	3.53	5	3.40
Benteng	No Take	4	3.63	3.33	3.79	3.38	2	3.39
Ujung Seurawan	No Take	5	3.56	2.92	4.05	3.23	3	3.34
Sumur Tiga	No Take	6	3.50	2.83	3.95	3.25	7	3.20
Jaboi	Use	7	3.47	3.25	3.74	2.44	6	3.08
Rubiah Sea Garden	No Take	8	3.34	3.00	3.68	3.32	8	3.21
Beurawang	Use	9	3.28	2.83	3.63	2.81	9	3.06
Lhong Angin 2	Use	10	3.28	3.08	3.42	2.67	14	2.86
Reuteuk	No Take	11	3.25	3.00	3.53	2.91	11	3.04
Gapang	No Take	12	3.13	2.92	3.37	2.84	13	2.96
Paloh	Use	13	3.09	2.58	3.42	3.28	12	3.12
Deudap	Use	14	3.09	3.00	3.16	2.53	10	2.95
Lhok Weng	Use	15	2.91	2.50	3.32	2.67	15	2.79
Pulau Klah	Use	16	2.84	2.08	3.42	2.85	16	2.83
Pasi Janeng 2	Use	17	2.75	2.92	2.84	2.28	19	2.37
Lamteng	Use	18	2.69	2.75	2.84	2.25	17	2.55
Leun Balee 1	Use	19	2.59	2.00	3.00	1.94	18	2.39

Table 6: Average scores (from highest to lowest) of factors managers can influence.

Factor	Average ± SE
Dispersal barrier	5.00 ± 0.00
Destructive fishing	4.89 ± 0.07
Physical damage	4.42 ± 0.21
Pollution (chemical)	4.00 ± 0.26
Pollution (solid)	4.00 ± 0.24
Nutrient input	3.68 ± 0.25
Fishing pressure	3.58 ± 0.29
Turbidity/Sedimentation	3.53 ± 0.28
Herbivores	3.37 ± 0.27
Grazers/ Browzers	3.16 ± 0.29
Biodiversity	2.68 ± 0.28
Resources	2.68 ± 0.28
Environmental quality	2.37 ± 0.26
Piscivores	2.32 ± 0.20
Excavators	1.63 ± 0.24
Scrapers	1.32 ± 0.15

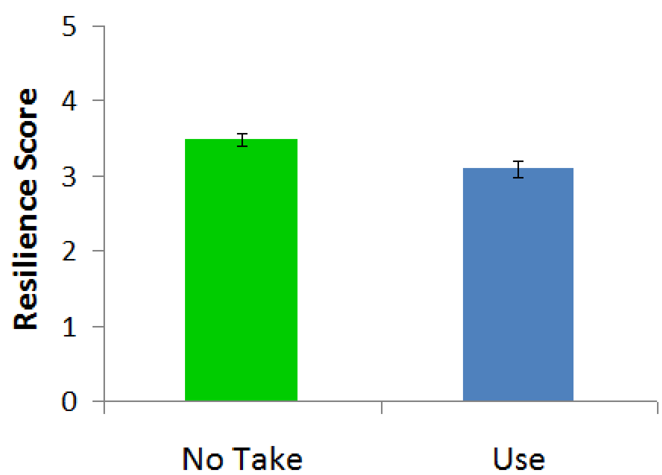

Figure 13. Average resilience scores for sites in Aceh currently designated as no take (green) and use (blue). The difference is statistically significant ($t_{17} = 2.501$, $p<0.05$).

Recommendations for Conservationists and Managers

The recommendations made below relate to Principles 1 and 2 of the four Principles in the TNC Resilience Model[5] - 1) representation and replication and 2) critical areas. Sites with high resilience are critical areas and protecting (representation in zoning plans) as many of these sites as possible (replication) will maximise the chances reefs have of coping with climate change,

[5] http://www.reefresilience.org/Intro_to_Resilience.html

particularly when connectivity is a consideration and the areas are effectively managed (principles 3 and 4 of the resilience model). Based on the analysis presented here, managers and conservationists could consider some or all of the following when targeting strategies and prioritising resource investment in Aceh.

- Establish Ba Kopra as a no-take area and actively implement management activities to reduce anthropogenic threats and maintain resilience. Ba Kopra has the highest resilience score, yet is currently designated as a use area, and has a medium management score. Protecting this site with the highest relative resilience and managing to mitigate threats could help maximise the number of healthy sites in the area as disturbance frequencies increase under the influence of both increasing human uses and climate change.
- Establish Jaboi as a no-take area. Jaboi has a medium resilience score and low scores for fishing pressure and herbivore and piscivore fish abundance, indicating that protection as a no-take zone may increase the capacity of this site to withstand and recover from disturbances.
- Prioritise the implementation of management strategies that reduce fishing pressure (on both herbivores and piscivores), possibly by increasing the amount of habitat designated no-take. This recommendation is common to most of our study MPAs because herbivore and piscivore abundance are the resilience indicators that managers can influence that frequently earned very low scores.

Managers are also likely to need to consider that sites assessed as having low or medium resilience may: a) have any of a range of other characteristics that make them critical areas, b) have habitats or species unique to the area and hence worthy of being represented in a park plan for that reason, or c) form a critical 'stepping stone' between resilient sites that are not in close proximity. This consideration, and the description provided above of the rationale for the recommendations, is only mentioned here but also applies to the other four area reports.

<u>Summary</u>

- The three sites in the Aceh area with the highest resilience scores are Ba Kopra Canyon and Ujung Seuke. The three sites with the lowest resilience scores are Pasi Janeng 2, Lamteng, and Leun Balee 1.
- Of the five sites with the highest resilience scores, four are designated as no-take areas in the current zoning plan. The average resilience score for sites currently designated no take is significantly greater than sites designated for use.
- The average score for factors relating to recovery is significantly greater than the average score for factors relating to bleaching resistance.
- Jaboi is the only site in the Aceh area that has a high or medium resilience score and a low score for the factors managers can influence. Managers and conservationists may want to consider implementing strategies to reduce anthropogenic stress at Jaboi in the coming years.

Bali/Lombok

Area Description

Bali and Lombok are adjacent islands located to the east of Java. Bali is surrounded by fringing reefs while the reefs studied on Lombok are located around the Gili Islands – a chain of three small islands in the north west of Lombok. All of these reefs are popular tourism destinations due to their high biodiversity and accessibility from the major tourism center of Denpasar. Important threats to these reefs are overfishing and coastal development due to the high coastal populations and high dependence on fishing. Some of the reefs in this area are managed either as government led MPAs such as Bali Barat National Park on the west coast of Bali and the Three Gilis in Lombok or community managed MPAs in Pemuteran Village and Lovina on the north coast of Bali.

Resilience, Bleaching Resistance and Recovery

The resilience scores range from a low of 2.50 (Labuan Lalang) to a high of 3.83 (Japanese Shipwreck; Table 7). The range of scores (1.33) was divided into three bins to categorise the resilience of each site relative to the other 27 sites surveyed in the area: low (2.50 – 2.94), medium (2.94 – 3.39), and high (3.39 – 3.83; shown as red, yellow and green, respectively in Table 7). The range of scores (from highest to lowest resilience score) is large relative to other areas in the study, indicating substantial differences between the capacity of sites in the area to resist bleaching and recover from disturbances.

Seventeen sites were classified as having low relative resilience, seven sites have medium resilience, and four sites have high resilience. The resilience scores calculated here as the average of the factors relating to bleaching resistance and recovery (Table 7) are similar to the scores calculated when all of the resilience factors recommended by IUCN (2009) are included. With either approach, the same three sites have the highest resilience scores in the same order and the same ten sites have the highest resilience scores, though the site ranking order changes slightly (Table 7).

The average score for factors relating to recovery (3.24 $\pm$ 0.07) is greater (t_{54} = 5.4211, $p<0.0001$) than the average score for factors relating to bleaching resistance (2.74 $\pm$ 0.06). There are no sites in the Bali/Lombok area in which the average score for factors relating to bleaching resistance is higher than the recovery score.

Table 7:. Average scores for resilience in Bali/Lombok (all factors relating to bleaching resistance and recovery), and these factor categories: bleaching resistance, recovery, and management. Sites are ranked from highest (1) to lowest resilience score (28). Colour bins shown are low, medium, and high relative classifications by column (see methods for more detail). The ranks and resilience scores (*) shown with asterisks are the analysis results found when all of the resilience factors recommended by IUCN (2009) are included. Marine park zones (*) in Bali/Lombok vary but are broadly classified here as 'No Take' and 'Use'; some regulations (i.e., quotas, gear or species restrictions) may exist in areas designated for use.

Site name	Marine Park Zoning	Rank	Resilience	Bleaching Resistance	Recovery	Management	Rank*	Resilience*
Japanese Shipwreck	No Take	1	3.83	3.17	4.32	3.09	1	3.70
Kelor	No Take	2	3.50	3.17	3.79	2.45	2	3.26
Wreck	No Take	3	3.43	3.08	3.74	3.10	3	3.41
Kotal	No Take	4	3.43	3.08	3.74	2.28	7	3.00
Lipah	Use	5	3.37	3.17	3.58	2.50	6	3.07
Halik	No Take	6	3.33	3.08	3.58	3.22	10	3.17
Penuktukan	No Take	7	3.30	2.83	3.68	3.44	5	3.46
Pura	No Take	8	3.23	2.92	3.53	3.10	4	3.39
Hans Reef	Use	9	3.03	2.92	3.21	2.56	9	2.98
Chill Out	Use	10	2.97	2.92	3.11	2.69	8	3.05
Villa Ombak	No Take	11	2.97	2.83	3.16	2.56	11	2.95
Kisik 1	Use	12	2.93	2.33	3.37	1.94	18	2.62
Pos I	No Take	13	2.90	2.67	3.16	2.67	14	2.92
Batu Kelebit	Use	14	2.87	2.92	2.95	3.03	13	3.06
Bondalem	No Take	15	2.87	2.58	3.16	2.47	25	2.68
Close Encounter	Use	16	2.87	2.75	3.00	2.19	17	2.71
Pos II	No Take	17	2.83	2.67	2.95	2.70	20	2.80
Jemeluk	Use	18	2.83	2.67	3.05	2.22	12	2.84
Napoleon Reef	Use	19	2.80	2.75	2.84	2.31	27	2.57
Coral Garden	No Take	20	2.77	2.67	2.95	3.88	19	3.17
Liberty	No Take	21	2.77	2.58	3.00	2.78	23	2.79
Meno Slope	Use	22	2.77	2.83	2.84	2.59	16	2.85
Tanjung Gelap	No Take	23	2.77	2.00	3.37	2.25	22	2.64
Lovina	Use	24	2.77	2.50	3.05	1.91	15	2.69
Tejakula	No Take	25	2.73	2.50	3.00	2.50	28	2.59
Sembiran	Use	26	2.73	2.33	3.11	1.88	21	2.53
Takat Saru	Use	27	2.63	2.58	2.79	2.78	24	2.78
Labuan Lalang	Use	28	2.50	2.33	2.63	2.89	26	2.78

Bleaching in 2010

Sites within this area experienced bleaching in 2010 following a severe thermal anomaly. 26 sites were surveyed for bleaching *and* assessed for resilience. There is no relationship between resistance score (R^2 = 0.10) and the % of colonies affected by bleaching (see Figure 14). This suggests that the *current* capacity of the resistance score to predict bleaching patterns is either limited generally or limited in this area, which could be due to one or a combination of the issues described at (c), (d), and (e) on page 18.

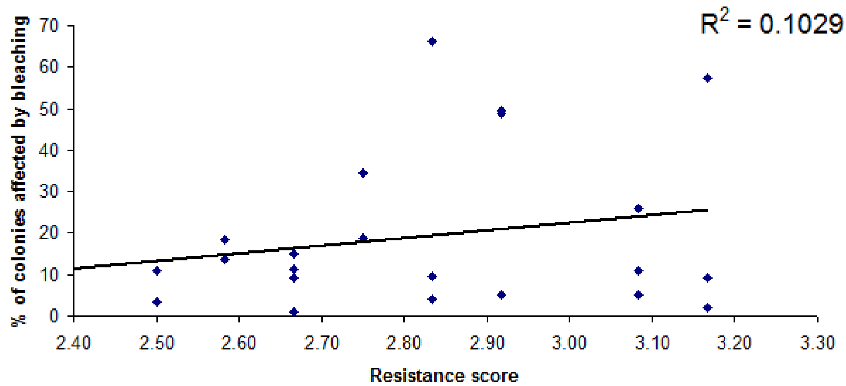

Figure 14. The relationship between resistance score and the % of colonies affected by bleaching in Bali/Lombok in May of 2010 is unclear and not that expected given bleaching severity increases (rather than decreases) slightly as resistance score increases.

Management

The average resilience score for sites currently designated no take (3.11 ± 0.09) is greater (t_{26} = 2.356, $p<0.05$) than sites where designated for use (2.85 ± 0.08; Figure 15). The four sites with the highest resilience scores are protected as no-take areas (Table 7). Three of the four sites with the lowest resilience scores are designated as limited fishing. Fishing is only permitted in two sites – Kelor, and Lipah – that have high or medium resilience and a low score for factors managers can influence. These results indicate that, to an extent, the current marine park zoning scheme already takes resilience into consideration. Specific recommendations to further increase the resilience of this group of sites through revisions to the zoning are offered in the section below.

For the 16 factors that managers can influence (see Table 4), the four factors with the lowest average scores all relate to fish: 'Grazers/Browsers' (2.04 ± 0.20), 'Scrapers' (1.79 ± 0.25), 'Piscivores' (1.79 ± 0.20) and 'Excavators' (1.25 ± 0.15) (see Table 8). This result and anecdotal evidence strongly suggests that fishing restrictions (gear, species, and space) are not complied with. This is true to an extent for all of the areas here so improving compliance is a management and conservation priority archipelago-wide.

Table 8: Average scores (from highest to lowest) for factors that managers can influence.

Factor	Average ± SE
Dispersal barrier	5.00 ± 0.00
Destructive fishing	4.75 ± 0.10
Fishing pressure	4.25 ± 0.21
Pollution (chemical)	4.18 ± 0.09
Biodiversity	3.32 ± 0.13
Resources	3.32 ± 0.14
Nutrient input	3.00 ± 0.17
Environmental quality	3.11 ± 0.11
Turbidity/Sedimentation	3.04 ± 0.17
Pollution (solid)	2.82 ± 0.19
Herbivores	2.36 ± 0.21
Physical damage	2.11 ± 0.18
Grazers/ Browzers	2.04 ± 0.20
Scrapers	1.79 ± 0.25
Piscivores	1.79 ± 0.20
Excavators	1.25 ± 0.15

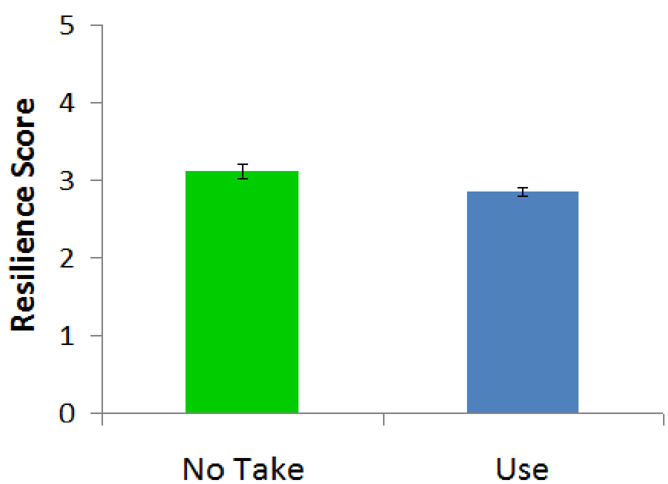

Figure 15. Average resilience scores for sites in the Bali/Lombok area currently designated as no take (green) and use (blue). The difference is statistically significant ($t_{26} = 2.356$, $p<0.05$).

Recommendations for Conservationists and Managers

Based on the analysis presented here, managers and conservationists could consider some or all of the following when targeting strategies and prioritising resource investment in Bali/Lombok. The rationale for these recommendations is on page 13 and other important considerations when including resilience as a consideration in management and conservation decisions is on page 28.

- Establish Lipah as a no-take area. Lipah has the fifth highest resilience score yet is currently designated as a limited fishing area. Additionally, its low score for herbivores, particularly for excavators and scrapers, indicate this site may benefit from reductions in fishing pressure.

- Increase the effectiveness of management at Japanese Shipwreck, Wreck, Kelor and Kotal to maintain resistance and recovery potential. All five sites have high resilience scores and are designated as no-take areas, but have some of the lowest scores in the area for fish abundance.
- Prioritise the implementation of management strategies that reduce fishing pressure (particularly on herbivores) and prevent physical damage from anthropogenic stress.

Summary

- The three sites in the Bali/Lombok area with the highest resilience scores are Japanese Shipwreck, Kelor and Wreck (tied with Kotal). The three sites with the lowest resilience scores are Sembiran, Takat Saru and Labuan Lalang.
- Of the eleven sites with the highest resilience scores, eight are designated as no-take areas in the current zoning plan. The average resilience score for sites currently designated no take is significantly greater than sites designated for use.
- The average score for factors relating to recovery is significantly greater than the average score for factors relating to bleaching resistance (see conclusions section for text on possibility of ranking sites based on recovery potential).
- Kelor, Kotal and Lipah are the only sites in the Bali/Lombok area that have a high or medium resilience score and a low score for the factors managers can influence. Managers and conservationists may want to consider implementing strategies to reduce anthropogenic stress at these sites in the coming years.

Karimunjawa

Area Description

Karimunjawa Islands are located in the Java Sea, north of Jepara in Central Java. The reefs within the park are in the best condition of all in the Java Sea. In 1999, 22 of the 27 islands in this area were designated as a national park with a total area of 111,625 ha. Karimunjawa National Park (KNP) protects five important ecosystems; tropical rain forest, beach forest, mangroves, seagrass beds and coral reefs. 55% of the population of 8732 are fishers (Jepara District Statistics Agency, 2010) and highly dependent on marine resources. The current zoning plan (revised in 2005) includes two no-take zones; core zone (no take, no entry) and protection zone (no take, limited entry), which altogether encompass 25% of the coral reefs and seagrass beds in the park. The remainder of the park is designated as traditional use for local residents, tourism, rehabilitation, and mariculture and is open to fishing and other activites.

Resilience, Bleaching Resistance and Recovery

The resilience scores range from a low of 2.67 (Katang 1) to a high of 4.07 (Karang Kapal; Table 9). The range of scores (1.40) was divided into three bins to categorise the resilience of each site relative to the other 42 sites surveyed in the area: low (2.67 – 3.13), medium (3.13 – 3.60), and high (3.60 – 3.4.07; shown as red, yellow and green, respectively in Table 9). The range of scores (from highest to lowest resilience score) is large relative to other areas in the study, indicating substantial differences between the capacity of sites in the area to resist bleaching and recover from disturbances.

Ten sites were classified as having low relative resilience, 31 sites have medium resilience, and two sites have high resilience. The resilience scores calculated here as the average of the factors relating to bleaching resistance and recovery (Table 9) are quite different to the scores calculated using all of the resilience factors recommended by IUCN (2009). While two of the three sites with both the highest and lowest resilience are the same for each method, there are a lot of differences in the results produced using the two methods. For instance, Kumbang 2 is ranked as the 30th highest resilience site if using the IUCN scores, yet is ranked 5th using the resilience analysis presented here. Further, Menjangan Besar is ranked as the 3rd highest resilience site if using the IUCN scores, yet is ranked 19th using the resilience analysis (Table 9).

The average score for factors relating to recovery (3.49 $\pm$ 0.04) is greater ($t_{84} = 6.796$, $p<0.001$) than the average score for factors relating to bleaching resistance (3.03 $\pm$ 0.06). Karang Kapal (the site with the highest resilience), Burung, Tanjung Lemu and Kumbang are the only sites in which the average score for factors relating to bleaching resistance was greater than the average score for factors relating to recovery (Table 9).

Table 9: Average scores for resilience in Karimunjawa (all factors relating to bleaching resistance and recovery), and these factor categories: bleaching resistance, recovery, and management. Sites are ranked from highest (1) to lowest resilience score (43). Colour bins shown are low, medium, and high relative classifications by column (see methods for more detail). The ranks and resilience scores shown with asterisks are the analysis results when all of the resilience factors recommended by IUCN (2009) are included. Marine park zones (*) in Karimunjawa vary but are broadly classified here as 'No Take' and 'Use'; some regulations (i.e., quotas, gear or species restrictions) may exist in areas classified as Use.

Site name	Marine Park Zoning	Rank	Resilience	Bleaching Resistance	Recovery	Management	Rank*	Resilience*
Karang Kapal	Use	1	4.07	4.25	4.00	3.41	1	3.72
Bengkoang	Use	2	3.67	3.50	3.79	2.63	5	3.38
Karang Katang	Use	3	3.57	3.33	3.74	3.00	2	3.56
Cendekian	Use	4	3.57	3.33	3.74	2.31	16	3.19
Kumbang 2	No Take	5	3.53	3.50	3.58	3.69	30	3.41
Gelean	No Take	6	3.53	3.33	3.58	2.72	14	3.30
Cemara Kecil 1	No Take	7	3.53	3.08	3.84	2.53	9	3.31
Menjangan Kecil	Use	8	3.53	3.25	3.68	2.22	8	3.21
Kumbang 3	No Take	9	3.50	3.33	3.63	3.59	4	3.64
Cemara Besar 1	Use	10	3.50	3.00	3.84	3.03	13	3.43
Sintok 1	No Take	11	3.50	3.08	3.79	3.00	22	3.37
Tanjung Sekoci	No Take	12	3.50	3.25	3.63	2.84	6	3.43
Taka Menyawakan W	No Take	13	3.50	3.25	3.68	2.72	23	3.27
Cemara Besar 2	Use	14	3.47	3.00	3.79	3.16	12	3.46
Cemara Kecil 2	No Take	15	3.47	3.08	3.74	2.53	17	3.24
Nyamuk	Use	16	3.43	3.42	3.47	2.50	10	3.30
Taka Menyawakan E	No Take	17	3.40	3.08	3.58	2.91	26	3.28
Sintok 2	No Take	18	3.40	3.17	3.58	2.88	15	3.39
Menjangan Besar	Use	19	3.40	3.00	3.63	2.50	3	3.37
Gosong Selikur 2	No Take	20	3.33	2.92	3.63	3.47	19	3.52
Tanjung Dua	No Take	21	3.33	3.25	3.37	3.28	20	3.45
Burung	No Take	22	3.33	3.33	3.26	3.22	29	3.29
Menyawakan	Use	23	3.33	3.00	3.53	2.84	11	3.42
Genting 3	Use	24	3.33	2.83	3.63	2.47	7	3.29
Genting 1	Use	25	3.33	3.00	3.53	2.41	18	3.19
Legon Janten	No Take	26	3.27	3.17	3.32	3.47	28	3.39
Legon Moto	No Take	27	3.27	3.17	3.32	2.91	24	3.32
Gosong Selikur 1	No Take	28	3.23	2.92	3.47	3.03	21	3.39
Genting 2	Use	29	3.23	3.00	3.37	2.97	33	3.17
Tanjung Lemu	Use	30	3.23	3.25	3.21	2.78	25	3.26
Kembar	Use	31	3.20	2.83	3.47	3.44	34	3.34
Kumbang 1	No Take	32	3.20	3.25	3.21	3.03	41	3.05
Tengah	Use	33	3.17	2.58	3.53	2.59	32	3.11
Kecil	Use	34	3.10	2.67	3.37	2.56	37	3.06
Taka Malang W	No Take	35	3.03	2.67	3.32	3.03	36	3.21
Pantai Nirwana	Use	36	3.03	2.58	3.32	3.03	27	3.27
Katang 2	No Take	37	3.03	2.58	3.32	2.50	38	3.00
Taka Malang E	No Take	38	3.00	2.58	3.26	3.84	40	3.39
Gosong Tengah	No Take	39	3.00	2.42	3.37	2.19	31	2.98
Parang 1	Use	40	2.93	2.75	3.00	2.84	39	3.08
Parang 2	Use	41	2.87	2.58	3.00	2.47	35	3.00
Batu Putih	Use	42	2.80	2.33	3.11	3.22	42	3.10
Katang 1	No Take	43	2.67	2.25	2.89	2.50	43	2.78

Bleaching in 2010

Surveys for bleaching and bleaching-induced mortality were not undertaken in 2010 in Karimunjawa because thermal stress levels were not high enough to cause thermal bleaching (see Figure 10). For this reason, we could not test for a relationship between bleaching resistance and bleaching severity in this area, as was done for Aceh, Wakatobi and Bali.

Management

The average resilience score for sites currently designated no take (3.32 $\pm$ 0.05) is not significantly different (t_{41} = 0.035, p>0.05) from sites designated for use (3.32 $\pm$ 0.06; Figure 16). Only one of the five sites with the highest resilience scores is protected as a no-take area in the current zoning plan (see Table 10). Five of the low resilience sites are no-take areas. These results suggest that making resilience a primary consideration during future re-zonings of this park would require many changes be made in the current zoning.

For the 16 factors that managers can influence (see Table 4), the four factors with the lowest average scores all relate the herbivorous fish: 'Herbivores' (2.37 $\pm$ 0.18), 'Grazers/Browsers' (1.95 $\pm$ 0.14), 'Scrapers' (1.60 $\pm$ 0.16) and 'Excavators' (1.53 $\pm$ 0.13, Table 10). Twelve sites (more than any other area) – Bengkoang, Cendekian, Gelean, Cemara Kecil 1, Menjangan Kecil, Taka Menyawakan W, Cemara Kecil 2, Nyamuk, Menjangan Besar, Genting 3, Genting 1 and Tengah – are classified as having high or medium resilience and a low score for factors managers can influence.

Table 10: Average scores (from highest to lowest) for factors that managers can influence.

Factor	Average $\pm$ SE
Destructive fishing	5.00 $\pm$ 0.00
Dispersal barrier	5.00 $\pm$ 0.00
Physical damage	4.33 $\pm$ 0.09
Pollution (solid)	4.21 $\pm$ 0.08
Pollution (chemical)	4.16 $\pm$ 0.09
Turbidity/Sedimentation	3.44 $\pm$ 0.12
Fishing pressure	3.35 $\pm$ 0.12
Nutrient input	3.21 $\pm$ 0.14
Piscivores	2.91 $\pm$ 0.14
Biodiversity	2.70 $\pm$ 0.13
Environmental quality	2.70 $\pm$ 0.13
Resources	2.70 $\pm$ 0.13
Herbivores	2.37 $\pm$ 0.18
Grazers/ Browzers	1.95 $\pm$ 0.14
Scrapers	1.60 $\pm$ 0.16
Excavators	1.53 $\pm$ 0.13

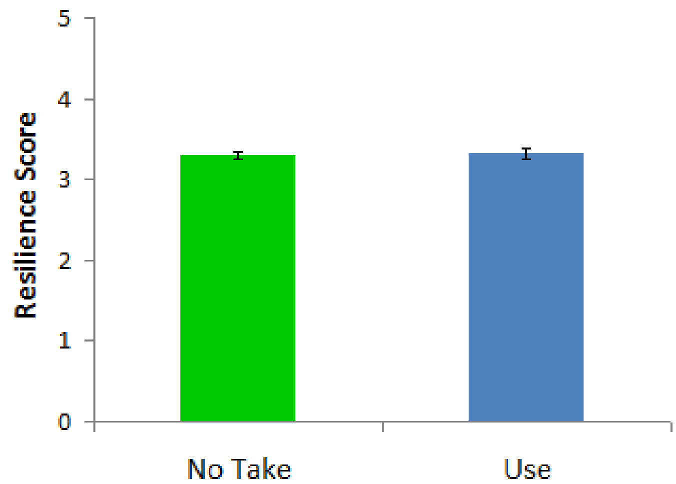

Figure 16. Average resilience scores for sites in the Karimunjawa area currently designated as no-take (green) and other areas designated for use (blue). The differences are not statistically significant (t_{41} = 0.035, p>0.05).

Recommendations for Conservationists and Managers

Based on the analysis presented here, managers and conservationists could consider some or all of the following when targeting strategies and prioritising resource investment in Karimunjawa. The rationale for these recommendations is on page 13 and other important considerations when including resilience as a consideration in management and conservation decisions is on page 28.

- Prioritise the implementation of management strategies that reduce fishing pressure (particularly on herbivores) and preserve local biodiversity, possibly by increasing compliance with no take areas to the extent possible.
- Establish Bengkoang, Karang Kapal, Cendekian and Menjangan Kecil as no-take areas. These four sites are among the sites with the highest resilience scores yet are currently designated for use. Additionally, three of these sites have low scores for management (Beng Koang, Cendekian and Menjangan Kecil). Eight other sites have medium resilience scores and low scores for management. More than any other area, the analysis for this area indicates that the current zoning regime does not protect many resilient sites as no-take areas.
- Increase compliance with fishing restrictions to the extent possible at Gelean, Cemara Kecil 1 and Menjangan Kecil. These sites are designated as no take, have a medium resilience score and low scores for 'herbivores' and 'piscivores'.

Summary

- The four sites in the Karimunjawa area with the highest resilience scores are Karang Kapal, Bengkoang, Karang Katang and Cendekian. The three sites with the lowest resilience scores are Parang 2, Babu Putih and Katang 1.
- Of the five sites with the highest resilience scores, only one (Kumbang 2) is designated as a no-take area in the current zoning plan. The average resilience score for sites currently designated no take is not significantly different from resilience scores for sites designated for use.

    - The average score for factors relating to recovery is significantly greater than the average score for factors relating to bleaching resistance.

- Twelve sites have high or medium resilience scores and low scores for management (more than any other area): Bengkoang, Cendekian, Gelean, Cemara Kecil 1, Menjangan Kecil, Taka Menyawakan W, Cemara Kecil 2, Nyamuk, Menjangan Besar, Genting 3, Genting 1 and Tengah. Managers and conservationists may want to consider implementing strategies to reduce anthropogenic stress at these sites in the coming years.

Kofiau

Area Description

Kofiau is located in the western portion of Raja Ampat, West Papua and consists of one major island (Kofiau Besar) and 42 smaller islands. Kofiau MPA was declared as part of the Raja Ampat MPA network in 2007 and encompasses 110,000 hectares of land and sea. Reefs are highly diverse and support reef fisheries. The population of Kofiau is low with 2,800 people living in three small villages located north of the main island of Kofiau. Traditional tenurial rights exist over both the land and sea areas although traditional management practices 'sasi' are no longer strongly implemented. Kofiau residients are both farmers and fishers and the main threat to marine resources is from destructive fishing and illegal and overfishing by outsiders. A zoning plan for the MPA is currently being developed and will include zones for non-extractive use and sustainable use such as artisinal fishing and aquaculture.

Resilience, Bleaching Resistance and Recovery

The resilience scores range from a low of 3.14 (Rataitapor) to a high of 3.55 (Boo Barrier Reef; Table 11). The range of scores (0.41) was divided into three bins to categorise the resilience of each site relative to the other 30 sites surveyed in the area: low (3.14 – 3.28), medium (3.28 – 3.41), and high (3.41 – 3.55; Table 11). The range of scores (from highest to lowest) is small relative to other areas in the study, indicating a high degree of similarity between sites in their capacity to resist bleaching and recover from disturbances.

Eight sites were classified as having low relative resilience, 14 sites have medium resilience, and nine sites have high resilience. The site rankings and resilience scores calculated here based on the average of the factors relating to bleaching resistance and recovery (Table 11) are vastly different from the scores calculated when all of the resilience factors recommended by IUCN (2009) are included. For example, the site with the highest score when all factors recommended by IUCN (2009) are included has only the 20th highest resilience score using the methods presented here. The site with the highest resilience score using the methods presented here – Boo Barrier Reef, only ranked 11th in the analysis that used all factors recommended by IUCN (2009). For other differences between the scores and rankings produced using each of the methods, see Table 11.

Uniquely to this area, the average score for factors relating to recovery (3.27 $\pm$ 0.03) is less than (t_{60} = 5.659, $p<0.001$) the average score for factors relating to bleaching resistance (3.50 $\pm$ 0.03). Tomna, with high relative resilience, is the only site in which the average score for factors relating to bleaching resistance was less than (only by 0.12) the average score for factors relating to recovery.

Table 11: Average scores for resilience in Kofiau (all factors relating to bleaching resistance and recovery), and these factor categories: bleaching resistance, recovery, and management. Sites are ranked from highest (1) to lowest resilience score (31). Colour bins shown are low, medium, and high relative classifications by column (see methods for more detail). The ranks and resilience scores shown with asterisks are the analysis results when all of the resilience factors recommended by IUCN (2009) are included. Proposed marine park zones (*) in Kofiau vary but are broadly classified here as 'No Take' and 'Use'; some regulations (i.e., quotas, gear or species restrictions) may be in place in future years in areas that are proposed use areas.

Site name	Proposed Marine Park Zoning	Rank	Resilience	Bleaching Resistance	Recovery	Management	Rank*	Resilience*
Boo Barrier Reef	No Take	1	3.55	3.91	3.42	3.78	11	3.77
Taroiukoyer	No Take	2	3.53	3.59	3.58	3.63	5	3.75
Cina	No Take	3	3.50	3.59	3.53	3.13	4	3.61
Karabas	Use	4	3.47	3.68	3.42	3.88	20	3.69
Tomna	No Take	5	3.47	3.41	3.53	3.63	6	3.75
Yenimfan	Use	6	3.47	3.59	3.47	3.03	10	3.56
Gebe Kecil	No Take	7	3.45	3.64	3.42	3.00	26	3.37
Warmaret	Use	8	3.43	3.59	3.42	2.78	29	3.27
Wamei	No Take	9	3.41	3.64	3.37	3.59	17	3.63
Warmariar	Use	10	3.40	3.50	3.37	3.00	12	3.55
Wambong Kecil	No Take	11	3.38	3.45	3.32	3.06	23	3.43
Taupadwar	No Take	12	3.36	3.59	3.26	3.50	7	3.70
Tolobi_2	Use	13	3.36	3.50	3.32	3.00	16	3.46
Tolobi_3	Use	14	3.36	3.59	3.32	3.00	13	3.53
Tanjung Deer	Use	15	3.33	3.50	3.26	2.50	28	3.21
Tapordoker	Use	16	3.33	3.59	3.26	2.78	8	3.49
Pamali	Use	17	3.31	3.45	3.26	3.78	18	3.68
Tanjung Lampu	Use	18	3.31	3.45	3.16	3.19	9	3.60
Walo	No Take	19	3.31	3.36	3.21	3.47	22	3.55
North Boo Kecil	No Take	20	3.29	3.68	3.16	4.00	1	3.90
Gebe Besar Wall	No Take	21	3.28	3.27	3.21	3.38	15	3.59
Tabek	Use	22	3.28	3.55	3.21	3.19	14	3.58
Yenpapir	No Take	23	3.28	3.36	3.16	3.69	3	3.79
Yenmandur	Use	24	3.26	3.59	3.16	2.72	19	3.37
Maet	No Take	25	3.24	3.27	3.16	3.81	2	3.84
Tolobi_1	Use	26	3.22	3.41	3.11	2.94	24	3.38
Gebe Besar	No Take	27	3.21	3.55	3.00	4.09	21	3.73
Twanyau Hner	Use	28	3.19	3.41	3.11	2.72	30	3.24
Kampung Deer	Use	29	3.17	3.27	3.21	2.59	25	3.26
Jailolo Besar	Use	30	3.16	3.23	3.00	3.44	31	3.44
Rataitapor	No Take	31	3.14	3.18	3.00	2.72	27	3.29

Bleaching in 2010

Surveys for bleaching and bleaching-induced mortality were not undertaken in 2010 in Kofiau because thermal stress levels were not high enough to cause thermal bleaching (see Figure 10). For this reason, we could not test for a relationship between bleaching resistance and bleaching severity in this area, as shown for Aceh, Wakatobi and Bali.

Management

The average resilience score for sites proposed for no take (3.36 $\pm$ 0.03) areas is not significantly different (t_{29} = 1.108, $p>0.05$) than sites that will be general use if the proposed zones are legislated (3.32 $\pm$ 0.02; Figure 17). The five sites with the highest resilience scores are all designated as no-take areas in the proposed zoning plan (see Appendix C). Three of the five sites with the lowest resilience scores will be unprotected if the proposed zoning is legislated. Therefore, even though the range in resilience scores is smallest for this area, the proposed zoning plan protects the sites the analyses presented here suggest have the highest resilience. However, seven sites – Gebe Kecil, Warmaret, Warmariar, Tolobi 2, Tolobi 3, Tanjung Deer and Tapordoker – are classified as having high or medium resilience and a low score for factors managers can influence. This indicates there are still actions managers can take to increase the resilience of sites in this area (see recommendations below).

For the 16 factors that managers can influence (see Table 4), the four factors with the lowest average scores all relate to fish. These are: 'Piscivores' (2.77 $\pm$ 0.20), 'Fishing Pressure' (2.74 $\pm$ 0.11), 'Herbivores' (2.58 $\pm$ 0.22) and 'Excavators' (1.87 $\pm$ 0.23) (see Table 12).

Table 12: Average scores (from highest to lowest) for factors that managers can influence.

Factor	Average $\pm$ SE
Dispersal barrier	5.00
Nutrient input	5.00
Physical damage	5.00
Pollution (chemical)	5.00
Pollution (solid)	5.00
Turbidity/Sedimentation	4.90 $\pm$ 0.10
Destructive fishing	4.26 $\pm$ 0.13
Grazers/ Browzers	3.10 $\pm$ 0.22
Scrapers	3.03 $\pm$ 0.22
Biodiversity	3.00
Environmental quality	3.00
Resources	3.00
Piscivores	2.77 $\pm$ 0.20
Fishing pressure	2.74 $\pm$ 0.11
Herbivores	2.58 $\pm$ 0.22
Excavators	1.87 $\pm$ 0.23

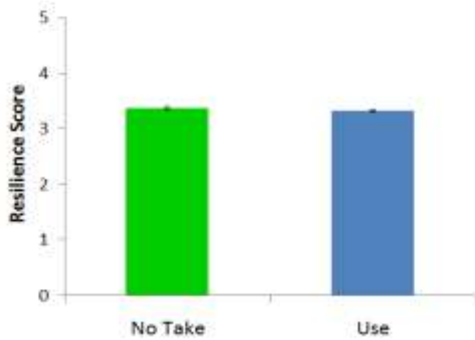

Figure 17. Average resilience scores for sites in the Kofiau area proposed as no-take areas (green) and areas proposed for use (blue). The difference is not statistically significant ($t_{29} = 1.108$, $p>0.05$).

Recommendations for Conservationists and Managers

Based on the analysis presented here, managers and conservationists *could consider* some or all of the following when targeting strategies and prioritising resource investment in Kofiau. The rationale for these recommendations is on page 13 and other important considerations when including resilience as a consideration in management and conservation decisions is on page 28.

- Prioritise the implementation of management strategies that reduce fishing pressure (on both herbivores and piscivores), possibly by increasing the amount of habitat designated no-take or increasing compliance with the proposed no-take areas to the extent possible.
- Establish Karabas, Yenimfan and Warmaret as no-take areas. These three sites have high resilience scores and are not proposed no-take areas in the draft plan. Warmaret also has a low management score, indicating this site in particular would benefit from reductions in anthropogenic stress. Gebe Kecil also has a high resilience score and a low management score, but is a proposed no-take area.
- Establish Warmariar, Tolobi 2, Tolobi 3, Tanjung Deer and Tapordoker as no-take areas. These sites have medium resilience, low management scores and are currently within areas proposed for use.

Summary

- The three sites in the Kofiau area with the highest resilience scores are Boo Barrier Reef, Taroiukoyer and Cina. The three sites with the lowest resilience scores are Kampung Deer, Jailolo Besar and Rataitapor.
- The five sites with the highest resilience scores are all designated as no-take areas in the proposed zoning plan. The average resilience score for sites designated no take in the proposed plan is not significantly different than sites proposed as use areas.
- Uniquely to this area, the average score for factors relating to recovery is significantly less than the average score for factors relating to bleaching resistance.
- Seven sites in the Kofiau area have a high or medium resilience score and a low score for the factors managers can influence: Gebe Kecil, Warmaret, Warmariar, Tolobi 2, Tolobi 3, Tanjung Deer and Tapordoker. Managers and conservationists may want to consider implementing strategies to reduce anthropogenic stress at these sites in the coming years.

Wakatobi

Area Description

The Wakatobi archipelago is located in Southeast Sulawesi, eastern Indonesia, and is named for the four major islands there: Wangi Wangi, Kaledupa, Tomia and Binongko. In 1996, 1.39 million hectares around Wakatobi was declared as a Marine National Park (WNP), comprising a total of 39 islands, surrounding mangroves, seagrass beds and coral reefs as well as large atolls and offshore areas. It is one of the most densely populated Marine National Parks in Indonesia with close to 100,000 residents recorded in 2007 (Wakatobi District statistics agency, 2008). Their dependency on marine resources is high, as most of the population are fishers, either as their main or secondary employment. The current zoning plan includes three types of non-extractive zones – core (no go, no take), marine protection (no take) and tourism (no take) which together encompass 2% of the park area but 37% of critical habitats. The remainder of the park is designated as traditional use zones around the islands for local residents and general use zones in offshore areas where commercial fishing is allowed. In the past, the reefs of WNP suffered extensive damage due to destructive fishing. Current threats to the health of coral reefs and sustainable fisheries in WNP are illegal and overfishing, and coral and sand extraction by local communities for construction materials.

Resilience, Bleaching Resistance and Recovery

The resilience scores[6] range from a low of 2.50 (Sampela) to a high of 3.17 (Table Coral City; Table 13). The range of scores (0.67) was divided into three bins to categorise the resilience of each site relative to the other 22 sites surveyed in the area: low (2.50 – 2.72), medium (2.72 – 2.94), and high (2.94 – 3.17); shown as red, yellow and green, respectively in Table 13). The range of scores (from highest to lowest resilience score) is small relative to other areas in the study, indicating substantial similarities between the capacity of sites in the area to resist bleaching and recover from disturbances. Note this is the only area where all resilience scores were estimated post bleaching as resources were not available to support the full assessments implemented at other sites.

Four sites were classified as having low relative resilience, 15 sites have medium resilience, and four sites have high resilience. The resilience scores calculated here as the average of the factors relating to bleaching resistance and recovery (Table 13) are very different to the scores calculated when all of the resilience factors recommended by IUCN (2009) are included. For

[6] For Wakatobi, a higher proportion of the resilience factors were estimated than measured in comparison to the other four regions.

example, the site with the second highest score when all factors recommended by IUCN (2009) are included has the 12th highest resilience score in the analysis presented here. For other differences in the scores and rankings produced by the two methods, see Table 13.

The average score for factors relating to recovery (3.03 ± 0.05) is greater ($t_{44} = 6.647$, $p<0.001$) than the average score for factors relating to bleaching resistance (2.62 ± 0.04). Buoy 3 (the site with the 3rd highest resilience) and Sampela (the site with the lowest resilience score) are the only two sites in which the average score for factors relating to bleaching resistance are greater than the average score for factors relating to recovery.

Bleaching in 2010

Sites within this area experienced bleaching in 2010 following a severe thermal anomaly. Only four sites were surveyed for bleaching and assessed for resilience during the desktop study; too low a sample size to test for a relationship between resistance scores and bleaching patterns (as shown for Aceh and Bali/Lombok in those sections).

Management

The average resilience score for sites currently designated no take (2.82 ± 0.04) is not significantly different ($t_{21} = 0.405$, $p = 0.69$) than sites designated for use (2.85 ± 0.06; Figure 18). Of the ten sites with the highest resilience scores, only half are designated as no-take areas in the current zoning plan; a result that is unique to this area (Appendix C). Further, four of the five sites with the lowest resilience scores are designated as no-take areas within the current zoning plan. These results indicate that resilience needs to be seriously considered as an information layer when revising zoning arrangements in the coming years.

For the 16 factors that managers can influence (see Table 4), the four factors with the lowest average scores are: ‘Pollution (solid)’ (1.78 ± 0.14), ‘Pollution (chemical)’ (1.70 ± 0.13), ‘Dispersal barrier’ (1.48 ± 0.15) and ‘Environmental quality’ (1.39 ± 0.14) (see Table 14). This is the only area in which the resilience analysis suggests coastal management/development are more pressing issues than fisheries management though this result does not suggest fisheries management is not also a critical issue. Only three sites – Laurent, Sombu and Blue Hole – are classified as having high or medium resilience (medium in this case) and a low score for factors managers can influence.

Table 13:. Average scores for resilience in Wakatobi (all factors relating to bleaching resistance and recovery), and these factor categories: bleaching resistance, recovery, and management. Sites are ranked from highest (1) to lowest resilience score (23). Colour bins shown are low, medium, and high relative classifications by column (see methods for more detail). The ranks and resilience scores shown with asterisks are the analysis results when all of the resilience factors recommended by IUCN (2009) are included.

Site name	Marine Park Zoning	Rank	Resilience	Bleaching Resistance	Recovery	Management	Rank*	Resilience*
Table Coral City	No Take	1	3.17	2.75	3.53	2.95	4	2.98
Ndaa East	Use	2	3.17	2.92	3.42	2.66	1	3.03
Buoy 3	No Take	3	2.97	3.08	2.95	3.23	13	2.99
Darawa South	Use	4	2.97	2.75	3.16	2.90	15	2.87
Ndaa West	Use	5	2.93	2.75	3.11	2.56	3	2.88
Bante	No Take	6	2.93	2.50	3.32	2.55	7	2.83
Laurent	No Take	7	2.93	2.75	3.11	2.36	11	2.75
Palahido	Use	8	2.90	2.67	3.11	2.67	9	2.85
Matahora North	Use	9	2.87	2.58	3.11	3.03	5	3.00
Matahora South	No Take	10	2.87	2.58	3.11	3.03	6	3.00
Pak Kasim's	No Take	11	2.87	2.67	3.05	2.85	14	2.86
Sombu	Use	12	2.87	2.25	3.21	2.41	2	2.93
Karang Kapota North	Use	13	2.80	2.58	3.00	2.71	8	2.87
Blue Hole	No Take	14	2.80	2.67	3.00	2.04	21	2.48
Waha	Use	15	2.77	2.75	2.84	3.05	20	2.84
Karang Kapota South	No Take	16	2.77	2.50	3.00	2.65	10	2.84
Pulau Sawa	Use	17	2.73	2.50	2.95	2.86	17	2.83
Gurita	No Take	18	2.73	2.58	2.89	2.79	12	2.87
Otiolo	No Take	19	2.73	2.42	3.00	2.46	16	2.73
Karang Kaledupa 3	No Take	20	2.70	2.33	3.00	2.77	18	2.78
Karang Kaledupa 2	No Take	21	2.63	2.33	2.89	2.21	19	2.61
Darawa North	No Take	22	2.60	2.75	2.58	2.21	22	2.44
Sampela	Use	23	2.50	2.58	2.47	2.14	23	2.32

Table 14: Average scores (from highest to lowest) for factors that managers can influence.

Factor	Average ± SE
Piscivores	3.43 ± 0.18
Herbivores	3.13 ± 0.11
Biodiversity	3.09 ± 0.14
Resources	3.00 ± 0.13
Grazers/ Browzers	3.00 ± 0.11
Scrapers	2.65 ± 0.10
Fishing pressure	2.52 ± 0.12
Physical damage	2.26 ± 0.11
Excavators	2.17 ± 0.12
Turbidity/Sedimentation	2.04 ± 0.16
Nutrient input	1.96 ± 0.18
Destructive fishing	1.91 ± 0.14
Pollution (solid)	1.78 ± 0.14
Pollution (chemical)	1.70 ± 0.13
Dispersal barrier	1.48 ± 0.15
Environmental quality	1.39 ± 0.14

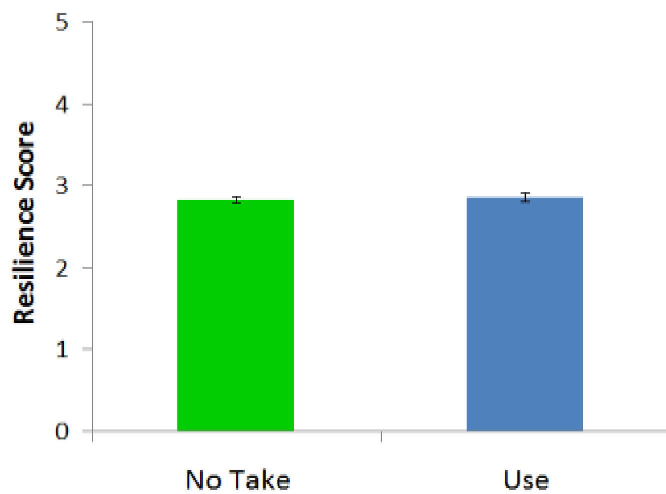

Figure 18. Average resilience scores for sites in the Wakatobi area currently designated as no take (green) and other areas designated for use (blue). The difference is not statistically significant (t_{21} = 0.405, p = 0.69).

Recommendations for Conservationists and Managers

Based on the analysis presented here, managers and conservationists *could consider* some or all of the following when targeting strategies and prioritising resource investment in Wakatobi:

- Assess and improve the existing zoning plan to include sites with higher resilience. The three sites surveyed for this project that are protected as no take areas are amongst the sites in the area with the lowest resilience.
- Prioritise the implementation of coastal management strategies that reduce the impacts of pollution and increase general environmental quality, possibly by evaluating point source and secondary pollution outflows.

- Establish Ndaa East and Darawa South as no-take areas. These two sites have high resilience scores, but neither of them is protected as a no-take area under the current zoning arrangement. Protecting sites with the highest relative resilience could help maximise the number of healthy sites in the area as disturbance frequencies increase under a regime of climate change.
- Assess and enhance the effectiveness of management at Laurent, Sombu and Blue Hole. These sites have medium resilience scores and management scores, indicating that improving the management actions already in place may increase the resilience of these sites (Laurent and Blue Hole are already designated no-take areas).

<u>Summary</u>

- The three sites in the Wakatobi area with the highest resilience scores are Table Coral City, Ndaa East, Buoy 3 and Darawa South. The three sites with the lowest resilience scores are Karang Kaledupa 2, Darawa North, and Sampela.
- Of the ten sites with the highest resilience scores, five are designated as no-take areas in the current zoning plan. The average resilience score for sites currently designated no take is not significantly different than sites designated for use.
- The average score for factors relating to recovery is significantly greater than the average score for factors relating to bleaching resistance.
- Laurent, Sombu and Blue Hole are the only sites in the Wakatobi area that have a high or medium resilience score and a low score for the factors managers can influence. Managers and conservationists may want to consider implementing strategies to reduce anthropogenic stress at these sites in the coming years.

Resilience and management across the archipelago

There are sites within each area that have high or medium resilience that are not protected by existing management zoning schemes. Additionally, each area contains sites with high or medium resilience that would benefit from further reductions in anthropogenic stress (Table 16). Both of these results indicate that the resilience of some sites in all areas can be increased by management strategies *already* being implemented across the archipelago. In this way, the presented results help to target actions and can serve as a valuable communications tool to help conservationists communicate the importance of resilience-based management to managers.

Importantly, the range in resilience scores for some areas is much larger (as much as double, or, in the case of Kofiau, triple) the range seen in other areas. Higher ranges indicate that resilience between sites in an area varies much more in some areas than others. Thus, in areas where the range in resilience scores is high relative to other areas, resilience may be more important to include as an information layer, i.e., sites within an area will vary more with respect to the effect of resilience on reef condition. Karimunjawa (1.40), Aceh (1.38) and Bali/Lombok (1.33) all have much higher ranges than Kofiau (0.41) and Wakatobi (0.67). Hence, in Karimunjawa, Aceh and Bali/Lombok, resilience-based management may be much more important than at Kofiau and Wakatobi where resilience scores are similar area-wide. In Aceh and Bali/Lombok, sites currently designated as no take areas had significantly higher ($p<0.05$) average resilience scores than sites designated for use (Figure 19). This indicates that the current zoning regime already protects most of the sites the analyses presented here suggest have high relative resilience. Differences were not significant in Karimunjawa, Kofiau or Wakatobi (see Figure 19). Given this, and that the range in resilience scores was high in Karimunjawa, reefs in this area would benefit most from including resilience as an information layer when revising the zoning scheme.

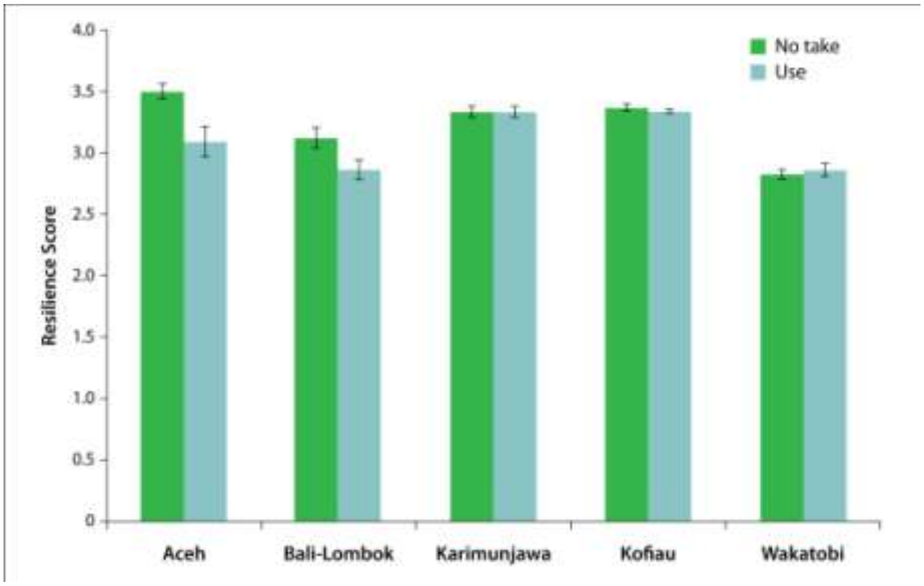

Figure 19. Resilience scores for each area of sites currently designated no take and use – use includes open access as well as other types of sites that might have use limitations but permit fishing. Differences in the average resilience scores for these site groupings in Aceh and Bali/Lombok are statistically significant.

Numerous sites within each area would benefit from further reductions in anthropogenic stressors such as unsustainable fishing pressure and improvements in general environmental quality along the coastal zones (Table 15). Five of the six factors that most frequently had the lowest average scores describe fish functional groups: four factors relate to herbivores and/or herbivorous fish functional groups and the other relates to piscivores. Thus, heavy fishing pressure is the anthropogenic stressor which most reduces the resilience of reef habitats in these five areas.

The average scores for recovery are greater than the average scores for bleaching resistance at four of the five study areas. This result indicates reefs in these four areas have a strong potential for recovery following disturbances but all sites will be under increasing pressure as the climate changes and the severity and frequency of disturbances increases. Maintaining the capacity to recover will require that managers protect the herbivorous fish functional groups likely to be critical to recovery process when disturbance frequencies increase.

Table 15: The factors of the 16 (out of 61 factors included in the IUCN resilience assessment protocol (2009) that had the four lowest average scores in each of the five study areas (marked with an X). The factors most frequently listed in the bottom four are shaded in grey.

Factor	Aceh	Bali - Lombok	Karimunjawa	Kofiau	Wakatobi
Biodiversity					
Destructive fishing					
Dispersal barrier					X
Environmental quality	X				X
Excavators	X	X	X	X	
Fishing pressure				X	
Grazers/ Browzers		X	X		
Herbivores			X	X	
Nutrient input					
Physical damage					
Piscivores	X	X		X	
Pollution (chemical)					X
Pollution (solid)					X
Resources					
Scrapers	X	X	X		
Turbidity / Sedimentation					

Table 16: Summary of resilience analysis results for all five study areas. The grey highlighted section summarises some of the recommendations for managers and conservationists posed in the reports provided for each study area. The assumption is made here that a key management goal is to maximise the number of healthy sites as the climate changes. The light grey column shows sites that are protected (or proposed to be protected; Kofiau) but would benefit from (further) reductions in anthropogenic stress, and the dark grey column shows sites with high or medium resilience that are currently designated for use (or proposed to be use areas; Kofiau). [* - see study area reports for statistics].

Site (n)	Highest/Lowest resilience score	Range	Number of high/medium/low resilience sites	Highest average scores (Bleaching resistance *or* Recovery)*	Medium/high resilience sites with low management scores	Number of high resilience sites currently designated for use
Aceh (19)	3.97, 2.59	1.38	5, 9, 5	Recovery	1 (Jaboi)	1 (Ba Kopra)
Bali - Lombok (28)	3.83, 2.50	1.33	4, 7, 17	Recovery	3 (Kelor, Kotal, Lipah)	0
Karimunjawa (43)	4.07, 2.67	1.40	2, 31, 10	Recovery	12 (Bengkoang, Cendekian, Gelean, Cemara Kecil 1, Menjangan Kecil, Taka Menyawakan W, Cemara Kecil 2, Nyamuk, Menjangan Besar, Genting 3, Genting 1 and Tengah)	2 (Karang Kapal, Bengkoang)
Kofiau (31)	3.55, 3.14	0.41	9, 14, 8	Bleaching Resistance	7 (Gebe Kecil, Warmaret, Warmariar, Tolobi 2, Tolobi 3, Tanjung Deer and Tapordoker)	3 (Karabas, Yenimfan, Warmaret)
Wakatobi (23)	3.17, 2.50	0.67	4, 15, 4	Recovery	3 (Laurent, Sombu, Blue Hole)	2 (Ndaa East, Darawa South)

Next steps - Recommendations for a revised resilience assessment protocol

This project's use and critical review of the IUCN (2009) resilience assessment protocol and the associated workshop process revealed that: assessing resilience can be made easier and less resource-intensive, that we can increase our collective confidence in the results, and that analysis results can be used to produce specific management recommendations. Our six specific recommendations for a revised resilience assessment protocol are below.

1. Criteria need to be developed for all of the factors assessed semi-quantitatively so that it is abundantly clear the conditions under which a site would be scored a 1, 2, 3, 4 and 5 for these factors (Table 17). Participants in the workshop in Bali in April, 2011 included ~15 field staff that have assessed the 61 factors used in the IUCN (2009) resilience assessment protocol and they concluded 16 (see Table 17) need improved criteria/guidelines to aid with assessment. Text in the IUCN (2009) protocol suggests users need to establish these criteria on their own, which we've done to standardise scoring here. This has been a time-intensive process though so establishing global criteria is likely to increase uptake and would ensure results from all resilience assessments would be comparable (even between reef regions). Methods for measuring the factors assessed quantitatively need to be recommended to help practitioners and, importantly, units for these factors (e.g., herbivore abundance) need to be standardised.

2. Factors that do not have to be semi-quantitatively (and subjectively) assessed (temperature variability being the key example shown here) should be quantitatively assessed whenever possible (e.g., through advances in the accessibility of high-resolution remotely sensed temperature data).

3. Factors need to be excluded that have limited relevance to the components of resilience that managers care about – bleaching resistance and recovery. Having fewer factors to estimate or measure increases the capacity of many groups to use the protocol and/or increases the frequency with which it is used to inform management decision-making. Further, excluding factors with limited relevance or that overlap others leading to potential double counting increases confidence in and credibility of the analysis results.

Table 17: Factors assessed semi-quanitatively that participants in our workshop in Bali in May, 2011 determined required better defined scoring criteria.

Factor name	
Sediment texture	Recovery-old
Branching residents	Nutrient input
Physical shading	Pollution (chemical)
Currents	Pollution (solid)
Topographic Complexity. - micro	Turbidity/Sedimentation
Top. Compl. - macro	Environmental quality
Physical damage	Currents
Biodiversity protection	Wave energy/ exposure

4. Researchers need to explore whether scaling the factors relating to resistance and recovery is justified. If factors that are critically important to resistance and recovery are scaled in the analysis they will not be diluted (through averaging) by scores that are of less relative importance (/relevance). Here, we demonstrate the limited capacity of the factors relating to bleaching resistance to predict bleaching patterns in two of the three study areas where bleaching was observed in 2010. We offered up five explanations for this result (see p. 26) that have been incorporated into the recommendations made in this section.

Note: At the time of publication, a manuscript led by TR McClanahan (that included authors represented here) was in the late stages of preparation that greatly advances recommendations 3 and 4 just above.

5. Investments in revising resilience assessment protocols need to be at least matched by investments in communicating the results to managers. Analysis results could be presented as shown in the results sections here whereby scores for bleaching resistance, recovery, and management (factors managers can influence) are all shown and categorised on a relative scale of low, medium, and high. This presentation makes the results accessible and easy to interpret. We have demonstrated that an automated template can be produced that presents results in the same format shown here; users need only input scores for the various resilience factors. Despite these advances, conservationists in many areas will first need to invest in educating managers about resilience concepts before discussing how resilience assessments can contribute to management decision-making. Such a training programs has been developed and is ongoing; the R^2 and Train the Trainers programs coordinated by TNC.

6. Resilience assessments need to be conducted/updated when the results can be incorporated in management decision-making processes like the zoning or re-zoning of a marine protected area. Since the zoning process can be protracted, conservationists need to communicate frequently with managers to determine the optimal timing of a resilience assessment. Further, data should be collected on all factors that can be assessed as part of a regular reef health monitoring program so that managers can track the dynamics of resilience at sites under their care.

7. Bleaching events create opportunities to learn more about the relationships between the various resilience factors and spatial variability in the severity of bleaching impacts, and also provide managers with up-to-date knowledge on reef condition. To facilitate this, response plans need to be established. These plans once operational need to have dedicated contingency funding that enables timely responses. On page 21 we describe the downsides of not conducting impact assessment surveys at the peak of bleaching as well as three months after (when it is possible to attribute mortality to a bleaching event).

Conclusion

Protecting resilient sites and targeting resilience-building management actions are critical actions managers should take as disturbances (like bleaching events) become more frequent and severe due to climate change and the increasing resource needs of a growing population. The results presented here clearly demonstrate that coral reef resilience assessments can be powerful tools that can inform management decision-making. For this to be possible, protocols need to be revised to be more focused and practical to use as well as to increase the robustness of their conclusions. To the extent possible, we have produced materials based on the results of this analysis to aid in mentoring and training coral reef managers and field practitioners. In the preceding section we provided tractable recommendations that our working group intends to incorporate into a revised protocol in the coming year. This protocol will follow on from the process and project results presented here in that with the revised protocol we will aim to: 1) increase the defensibility of resilience assessment analysis results, and 2) help conservationists communicate about resilience in ways that ensure managers understand what actions can and should be taken to maintain and support reef resilience.

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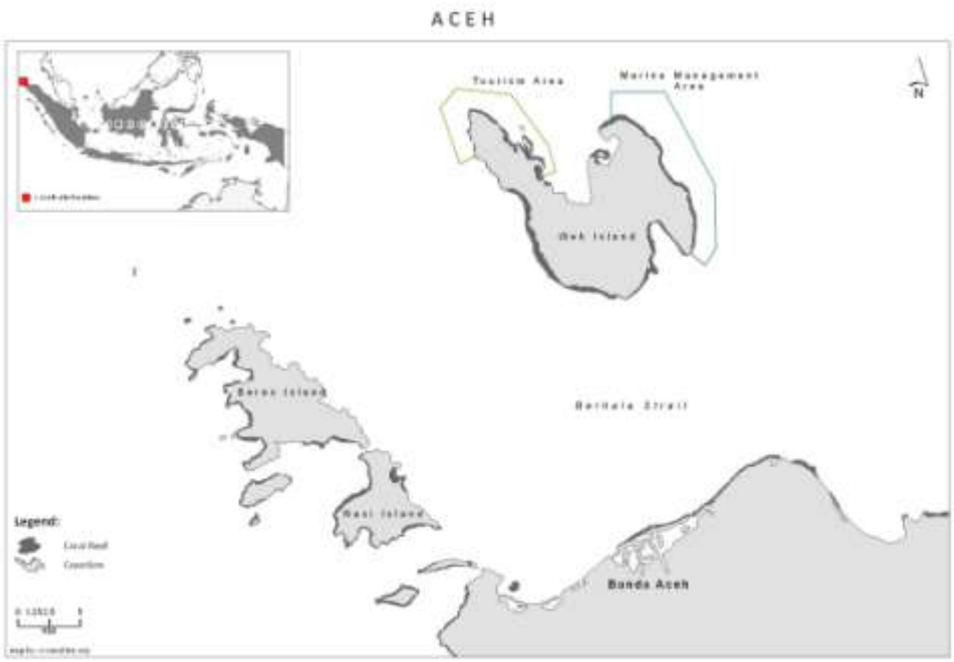
Appendix A. List of attendees at Bali Resilience Workshop 14-18 April 2011.

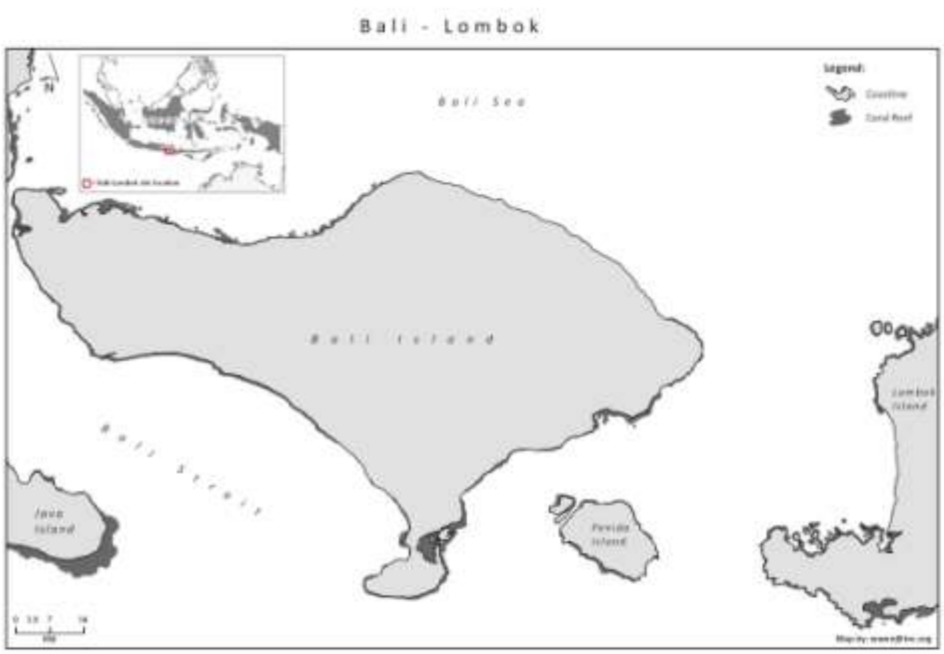
	Name	Organisation	Role
1	Jeff Maynard	Uni of Melb	Facilitator
2	Paul Marshall	GBRMPA	Facilitator
3	Joanne Wilson	TNC	Facilitator
4	Rod Salm	TNC	Advisor
5	Rizya Ardiwijaya	TNC	Co-lead Wakatobi
6	Sangeeta Mangubhai	TNC	Lead – Kofiau
7	Purwanto	TNC	Participant
8	Muhajir	TNC	Participant
9	Achmad Sahri	TNC	Participant
10	Andreas Muljadi	TNC	Participant
11	Rob Brumbaugh	TNC	Advisor
12	Naneng Setiaish	CORAL	Co-lead Bali
13	Jensi	ReefCheck	Co-lead Bali
14	Derta	ReefCheck	Participant
15	Rian	ReefCheck	Participant
16	Stuart Campbell	WCS	Lead Aceh
17	Rian	WCS	Participant
18	Yudi	WCS	Participant
19	Epon	WCS	Participant
20	Shinta	WCS	Participant

Appendix B. Maps of areas surveyed for resilience (2009) and bleaching impacts (2010) through the course of this study.

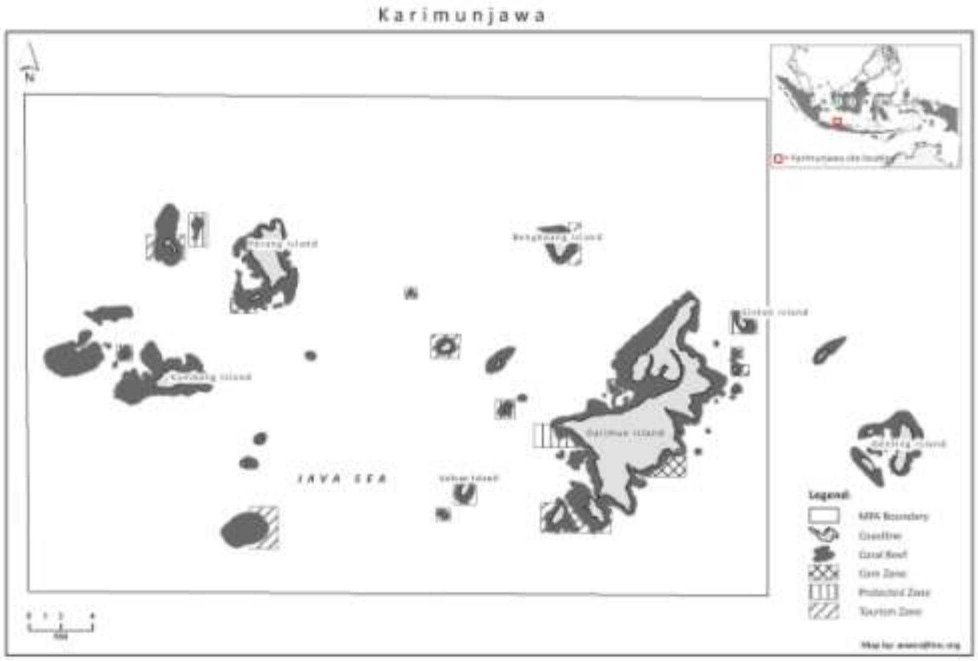
Aceh



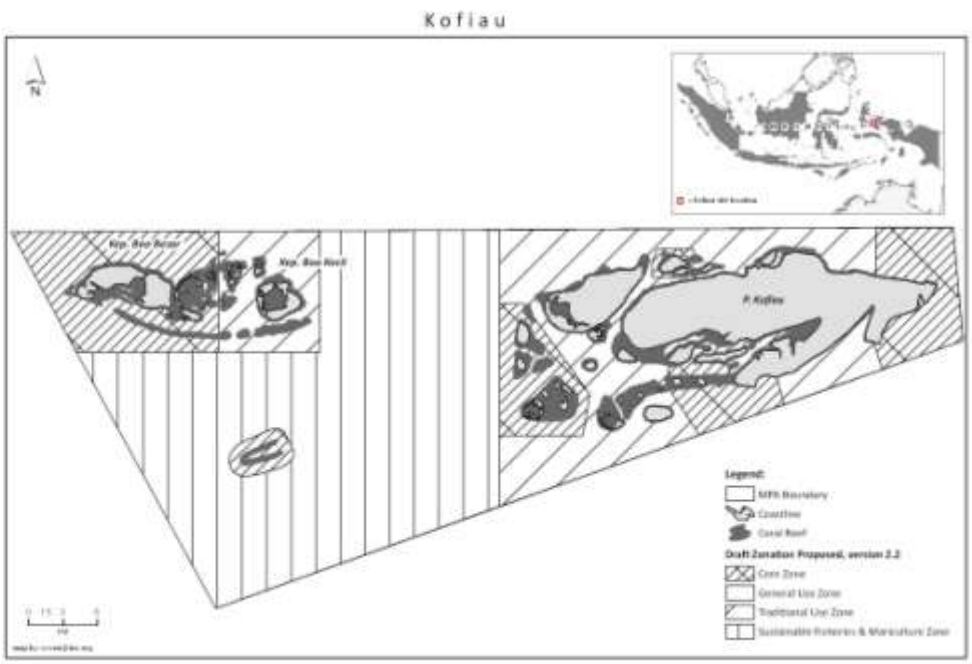
Bali/Lombok



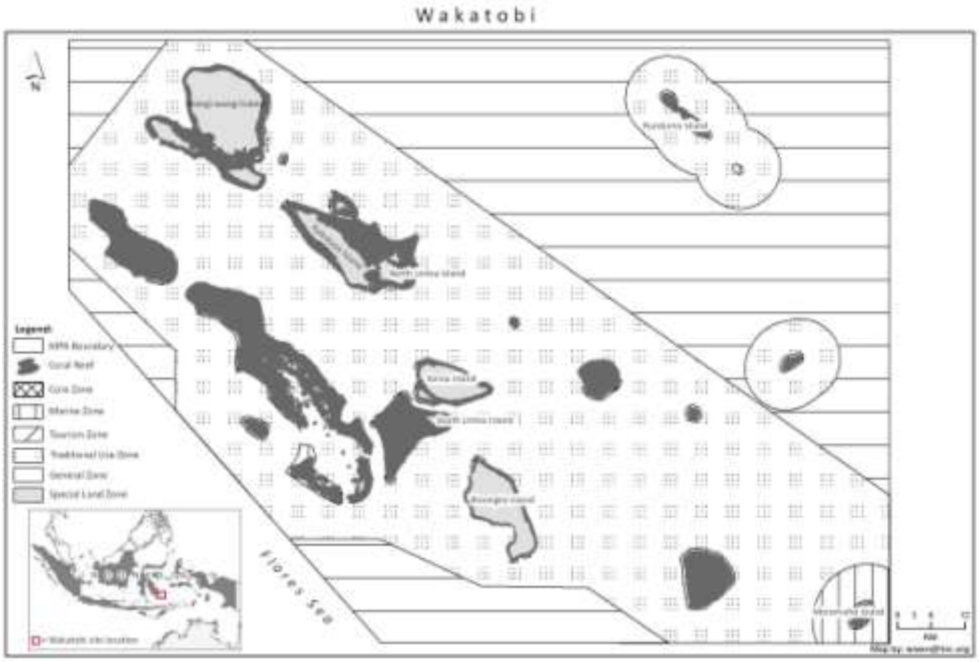
Karimunjawa



Kofiau



Wakatobi



Appendix C. Meeting conditions for statistical analysis: using resilience indicators to explain variability in bleaching response severity

The results of testing to meet condition 1 ($\geq$5% of colonies affected by bleaching) are shown in Table I. During the bleaching surveys, more than 5% of colonies in all areas were affected by bleaching; but <5% of colonies were affected by bleaching during the post-bleaching surveys in Wakatobi and Bali-Lombok (see results section on survey timing).

Table I. Result of test for meeting condition 1 (see text for more detail) whereby sites within a study area on average need to have more than 5% of colonies affected by bleaching (showing any signs of bleaching, including paling).

Survey timing	Study area	% of colonies affected by bleaching	At least 5% of colonies affected by bleaching?
Bleaching (April-June, 2010)	Aceh	92.95	Yes
	Bali/Lombok	17.72	Yes
	Wakatobi	62.63	Yes
Post-bleaching (July, 2010 - January, 2011)	Aceh	84.94	Yes
	Bali/Lombok	3.01	No
	Wakatobi	2.89	No

For these four datasets (see green in Table I) tests for condition 2 are shown below in Tables II-IV, with factors that meet the condition shown in green. Condition 2 is that there has to be sufficient variation in the scores for a factor to test whether the factor can predict bleaching response severity. There are a range of factors that meet condition 2 in Aceh (7 of 16, see Table II) and Bali/Lombok (12 of 16, see Table III). However, sample sizes (sites with bleaching survey data and resilience assessments) are too low in Wakatobi during the bleaching surveys (see red boxes across bottom of Table IV) to test whether any of the factors can predict patterns in bleaching severity.

Table II. Test for condition 2 (see text above) for the resilience assessment conducted in Aceh. Seven of the 16 have scores with sufficient variability to test for the capacity to predict bleaching responses.

	Score	Wave energy/ exposure	Deep water (30–50m)	Physical shading	Canopy corals	Exposed low tide	Ponding/pooling	Temperature variability	Nutrient input	Pollution (chemical)	Pollution (solid)	Turbidity/Sedimentation	Fishing pressure	Environmental quality	Dominant size class	Largest corals (3)	Herbivores
2 sites with this score?	1	No	No	Yes	No	Yes	Yes	No	No	No	No	No	Yes	No	No	No	No
2 sites with this score?	2	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	No	No	Yes
2 sites with this score?	3	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
2 sites with this score?	4	Yes	No	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2 sites with this score?	5	No	No	No	No	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No
At least 3 of the 5 potential scores have 2 sites with those scores?		No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes

Table **III.** Test for condition 2 for the bleaching survey (April-June 2010) data collected in Bali/Lombok. 12 of the 16 factors have sufficient variability to test for the capacity to predict bleaching responses.

	Score	Wave energy/ exposure	Deep water (30–50m)	Physical shading	Canopy corals	Exposed low tide	Ponding/pooling	Temperature variability	Nutrient input	Pollution (chemical)	Pollution (solid)	Turbidity/Sedimentation	Fishing pressure	Environmental quality	Dominant size class	Largest corals (3)	Herbivores
2 sites with this score?	1	Yes	No	Yes	No	Yes	Yes	No	No	No	No	No	No	No	No	No	Yes
2 sites with this score?	2	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	Yes
2 sites with this score?	3	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2 sites with this score?	4	No	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2 sites with this score?	5	No	No	No	Yes	No	No	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	No
At least 3 of the 5 potential scores have 2 sites with those scores?		Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table IV. Test for condition 2 for the bleaching survey (April-June 2010) data collected in Wakatobi. Sample sizes are low (4 sites) - there is not sufficient variation in scores for any of the factors to warrant testing for the capacity to predict bleaching severity.

	Score	Wave energy/ exposure	Deep water (30–50m)	Physical shading	Canopy corals	Exposed low tide	Ponding/pooling	Temperature variability	Nutrient input	Pollution (chemical)	Pollution (solid)	Turbidity/Sedimentation	Fishing pressure	Environmental quality	Dominant size class	Largest corals (3)	Herbivores
2 sites with this score?	1	No	No	No	No	Yes	No	No	Yes	Yes	Yes	No	No	Yes	No	No	No
2 sites with this score?	2	No	No	No	Yes	No	Yes	No	No	No	No	Yes	Yes	No	No	No	No
2 sites with this score?	3	No	No	Yes	No	No	No	Yes	No	No	No	No	Yes	No	Yes	No	Yes
2 sites with this score?	4	Yes	No	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No
2 sites with this score?	5	No	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No	No
At least 3 of the 5 potential scores have 2 sites with those scores?		No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No