Tutorial on Analyzing Relative Resilience

- This tutorial walks managers through the steps needed to analyze data on resilience indicators using a fictional reef system and simple analysis tools (e.g., MS Excel and mapping software such as ArcGIS). To make the analysis more realistic, the data included is based on actual field data from the Caribbean and Pacific.

Analyzing Relative Resilience

<u>Completing the analysis:</u>

STEP:

1. Compile all data collected for resilience indicators into a table
2. Anchor scores for each indicator for each site to the maximum value
3. Set a uni-directional scale for all indicators
4. Averaging anchored scores for all indicators
5. Anchoring the resilience scores to assess relative resilience
6. Ranking sites
7. Grading sites as having high, medium or low relative resilience
8. Assessing anthropogenic stress

<u>Presenting and interpreting the analysis results:</u>

STEP:

1. Using statistics to determine which indicators drive differences among sites
2. Presenting resilience analysis results
3. Interpreting analysis results to inform management

This tutorial describes the steps required to complete and interpret an analysis of relative resilience. 11 steps are described in total. The first 8 steps relate to completing the analysis, which can be done in MS Excel using simple formulas and sorting.

Completing the analysis:

STEP 1: For our example (on the next page), a fictional reef system has been created with 18 different reef sites. The names are fictional but the data are realistic and based on actual field data from the Caribbean and Pacific. The managers undertaking this analysis went through the process of selecting indicators described in the Coral Reef Module. Managers met with representatives of partner agencies and stakeholders and decided that 7 resilience indicators would be measured or assessed. The indicators selected are thought to be strongly related to resistance and recovery in the reef system and data could be collected on all indicators within the available resources, to a satisfactory standard, and using standardized methods at all sites. Data for 6 of the 7 (all but temperature variability) indicators were collected using field surveys conducted on SCUBA. Temperature variability data were provided by NOAA. All of the data for each of the resilience indicators has been compiled into a table using Excel. These are all raw data values.

For this very first step all of the data for each of the resilience indicators has been compiled into a table. These are all raw data values. Here, resistant coral species is the % of the coral community made up of species known to have greater relative resistance to temperature-induced bleaching, herbivore biomass values are kg/100m^2, and macroalgae and coral cover are percentages. Coral disease is assessed as the % of colonies affected by coral disease (i.e., disease prevalence). Temperature variability is the standard deviation of summer temperatures from 1985-2010 based on remotely sensed sea surface temperature data (NOAA Pathfinder v5.2). Coral diversity is assessed as the Simpson's Index of Diversity which tests the likelihood that two species randomly sampled in a population will be different; greater the likelihood (closer to 1) the greater the diversity.

STEP 1: Compile all data collected for resilience indicators into a table

Site	Resistant Coral Species	Temp Variability	Coral Diversity	Herbivore Biomass	Coral Disease	Macroalgae Cover	Coral Cover
Clam Reef	96.94	0.34	0.48	4.74	0.00	2.00	3.70
Coral Reef	74.18	0.31	0.78	29.70	0.00	2.60	14.38
Crab Reef	0.00	0.27	0.00	0.49	0.00	1.40	14.38
Dolphin Reef	50.89	0.27	0.69	8.87	0.00	16.90	1.64
Fish Reef	5.96	0.31	0.56	19.73	0.00	22.00	15.56
Lobster Reef	31.59	0.34	0.55	13.64	1.33	31.42	5.96
Nautilus Reef	15.00	0.34	0.59	0.56	0.20	19.38	3.90
Nudibranch Reef	7.73	0.31	0.58	4.09	0.00	0.10	2.00
Octopus Reef	100.00	0.33	0.00	0.02	0.00	6.40	1.34
Prawn Reef	20.74	0.34	0.75	0.19	0.00	76.30	17.00
Ray Reef	27.57	0.27	0.79	30.78	0.01	8.46	13.06
Sea Cucumber Reef	0.00	0.29	0.00	1.14	0.00	11.80	0.02
Sea Fan Reef	0.00	0.32	0.00	0.12	0.00	89.88	4.46
Shark Reef	46.48	0.31	0.87	27.91	0.00	0.32	2.84
Sponge Reef	96.15	0.35	0.52	9.79	0.00	10.24	0.02
Starfish Reef	0.00	0.34	0.00	1.66	0.00	22.02	1.96
Turtle Reef	47.02	0.30	0.83	31.77	0.00	0.10	8.68
Whale Reef	73.57	0.27	0.58	3.33	0.00	1.14	7.67

STEP 2: Data for each of the resilience indicators cannot be averaged together until all of the indicators have the same scale. This process is called ‘normalizing’ the data. See example on the next page.

We will normalize the data through a process called ‘anchoring’. The value for each indicator is anchored to the max value for that indicator across all sites by dividing by the maximum value.

Two examples of this process are shown in the table on the next page. 100% of the coral community at Octopus Reef is made up of resistant coral species. The values for resistant coral species for all other sites are then divided by 100, which creates a new decimal value for all sites that is a percentage of 1. At Octopus Reef 100/100 leaves Octopus Reef with the max possible score for ‘Resistant Coral Species’ of 1. Anchored scores for resistant coral species vary widely. Some sites like Clam and Sponge Reef have scores close to 1 while some other sites like Nudibranch and Fish Reef have scores close to 0. The highest data value for Coral Diversity is 0.87 (Shark Reef). Again, the values for all other sites are anchored to the max value of 0.87 by dividing by 0.87 leaving Shark Reef with a 1. As with Resistant Coral Species, the anchored scores for Coral Diversity vary widely with some sites having high scores close to 1 and other sites having scores of 0.

STEP 2: Anchor scores for each indicator for each site to the maximum value

Site	Resistant Coral Species	Resistant Coral Species Anchored	Coral Diversity	Coral Diversity Anchored
Clam Reef	96.94	0.97	0.48	0.55
Coral Reef	74.18	0.74	0.78	0.89
Crab Reef	0.00	0.00	0.00	0.00
Dolphin Reef	50.89	0.51	0.69	0.80
Fish Reef	5.96	0.74	0.56	0.64
Lobster Reef	31.59	0.32	0.55	0.64
Nautilus Reef	15.00	0.15	0.59	0.67
Nudibranch Reef	7.73	0.08	0.58	0.66
Octopus Reef	100.00	1.00	0.00	0.00
Prawn Reef	20.74	0.21	0.75	0.86
Ray Reef	27.57	0.46	0.79	0.91
Sea Cucumber Reef	0.00	0.00	0.00	0.00
Sea Fan Reef	0.00	0.00	0.00	0.00
Shark Reef	46.48	0.28	0.87	1.00
Sponge Reef	96.15	0.96	0.52	0.60
Starfish Reef	0.00	0.00	0.00	0.00
Turtle Reef	47.02	0.47	0.83	0.96
Whale Reef	73.57	0.06	0.58	0.67

STEP 3: Before the values for indicators can be averaged together, we have to make sure that the standard scale we have set through anchoring of 0 to 1 is unidirectional (i.e., a high score indicates high resilience). The prevalence of some of our indicators (high % of resistant coral species, high coral diversity) indicates greater resilience, while other indicators (high macroalgal cover, high coral disease) indicate less resilience.

To ensure that a high value (1) represents greater resilience, we have to subtract anchored scores from 1 for all resilience indicators that adversely affect resilience (e.g., macroalgae cover and coral disease). In the example here, Sea Fan Reef has 89.88% macroalgae cover. After anchoring, the value for macroalgae cover at Sea Fan Reef is 1. Since this is the max and worst score for our 18 reef sites, this value is subtracted from 1 leaving Sea Fan Reef with a final score of 0 and other sites with very low macroalgae cover like Clam Reef with scores close to 1 (0.98 for Clam Reef).

STEP 3: Set a uni-directional scale for all indicators

Site	Macroalgae Cover	Macroalgae Cover Anchored (MCA)	Macroalgae Cover FINAL (1-MCA)
Clam Reef	2.00	0.02	0.98
Coral Reef	2.60	0.03	0.97
Crab Reef	1.40	0.02	0.98
Dolphin Reef	16.90	0.19	0.81
Fish Reef	22.00	0.24	0.76
Lobster Reef	31.42	0.35	0.65
Nautilus Reef	19.38	0.22	0.78
Nudibranch Reef	0.10	0.00	1.00
Octopus Reef	6.40	0.07	0.93
Prawn Reef	76.30	0.85	0.15
Ray Reef	8.46	0.09	0.91
Sea Cucumber Reef	11.80	0.13	0.87
Sea Fan Reef	89.88	1.00	0.00
Shark Reef	0.32	0.00	1.00
Sponge Reef	10.24	0.11	0.89
Starfish Reef	22.02	0.24	0.76
Turtle Reef	0.10	0.00	1.00
Whale Reef	1.14	0.01	0.99

STEP 4: Once all of the scores have been anchored and the scale is unidirectional, we are ready to average the scores together to produce a resilience score for each site. To do this, you average the 7 resilience indicator scores for each reef site, shown on the next page, in the new column shaded grey.

STEP 4: Averaging anchored scores for all indicators

Site	Resistant Coral Species	Temp Variability	Coral Diversity	Herbivore Biomass	Coral Disease	Macroalgae Cover	Coral Cover	Resilience Score
Clam Reef	0.97	0.94	0.55	0.10	1.00	0.98	0.12	0.67
Coral Reef	0.74	0.86	0.89	0.60	1.00	0.97	0.48	0.79
Crab Reef	0.00	0.76	0.00	0.01	1.00	0.98	0.48	0.46
Dolphin Reef	0.51	0.76	0.80	0.18	1.00	0.81	0.06	0.59
Fish Reef	0.74	0.76	0.64	0.07	1.00	0.99	0.26	0.64
Lobster Reef	0.32	0.94	0.64	0.28	0.00	0.65	0.20	0.43
Nautilus Reef	0.15	0.94	0.67	0.01	0.85	0.78	0.13	0.51
Nudibranch Reef	0.08	0.85	0.66	0.08	1.00	1.00	0.07	0.53
Octopus Reef	1.00	0.91	0.00	0.00	1.00	0.93	0.05	0.56
Prawn Reef	0.21	0.94	0.86	0.00	1.00	0.15	0.57	0.53
Ray Reef	0.46	0.87	0.91	0.57	1.00	1.00	0.10	0.70
Sea Cucumber Reef	0.00	0.81	0.00	0.02	1.00	0.87	0.00	0.39
Sea Fan Reef	0.00	0.89	0.00	0.00	1.00	0.00	0.15	0.29
Shark Reef	0.28	0.76	1.00	0.63	0.99	0.91	0.44	0.71
Sponge Reef	0.96	0.97	0.60	0.20	1.00	0.89	0.00	0.66
Starfish Reef	0.00	0.94	0.00	0.03	1.00	0.76	0.07	0.40
Turtle Reef	0.47	0.84	0.96	0.65	1.00	1.00	0.29	0.74
Whale Reef	0.06	0.86	0.67	0.40	1.00	0.76	0.52	0.61

STEP 5: We call this an analysis of ‘relative resilience’ because we assess the resilience of each of the reef sites ‘relative’ to the other sites and, in particular, to the site with the highest resilience score. As we did with each indicator, we now need to anchor all resilience scores to the max value.

Anchoring the scores for all of the indicators does not mean that once averaged the resilience scores will be on a scale of 0-1. This would only occur if there was a site that had the max value (a 1) for each and every indicator. Re-anchoring ensures that all sites are assessed relative to the site with the max average score, which receives a 1.

Remember, the resilience scores are the average of scores for all of our resilience indicators. In this example, the highest resilience score is 0.79 for a site called ‘Coral Reef’. We divide the resilience scores for all sites by 0.79 leaving Coral Reef with the highest possible score of 1. All of the other sites now have a final anchored resilience score that expresses resilience as a decimal value percentage of 1. You can see that some sites like Shark Reef have scores close to 1 (0.90), while other sites have final anchored resilience scores that are much lower, like Sea Fan Reef (0.37).

STEP 5: Anchoring the resilience scores to assess relative resilience

Site	Resistant Coral Species	Temp Variability	Coral Diversity	Herbivore Biomass	Coral Disease	Macroalgae Cover	Coral Cover	Resilience Score	R Score_Anchored
Clam Reef	0.97	0.94	0.55	0.10	1.00	0.98	0.12	0.67	0.84
Coral Reef	0.74	0.86	0.89	0.60	1.00	0.97	0.48	0.79	1.00
Crab Reef	0.00	0.76	0.00	0.01	1.00	0.98	0.48	0.46	0.59
Dolphin Reef	0.51	0.76	0.80	0.18	1.00	0.81	0.06	0.59	0.74
Fish Reef	0.74	0.76	0.64	0.07	1.00	0.99	0.26	0.64	0.81
Lobster Reef	0.32	0.94	0.64	0.28	0.00	0.65	0.20	0.43	0.55
Nautilus Reef	0.15	0.94	0.67	0.01	0.85	0.78	0.13	0.51	0.64
Nudibranch Reef	0.08	0.85	0.66	0.08	1.00	1.00	0.07	0.53	0.68
Octopus Reef	1.00	0.91	0.00	0.00	1.00	0.93	0.05	0.56	0.70
Prawn Reef	0.21	0.94	0.86	0.00	1.00	0.15	0.57	0.53	0.68
Ray Reef	0.46	0.87	0.91	0.57	1.00	1.00	0.10	0.70	0.89
Sea Cucumber Reef	0.00	0.81	0.00	0.02	1.00	0.87	0.00	0.39	0.49
Sea Fan Reef	0.00	0.89	0.00	0.00	1.00	0.00	0.15	0.29	0.37
Shark Reef	0.28	0.76	1.00	0.63	0.99	0.91	0.44	0.71	0.90
Sponge Reef	0.96	0.97	0.60	0.20	1.00	0.89	0.00	0.66	0.83
Starfish Reef	0.00	0.94	0.00	0.03	1.00	0.76	0.07	0.40	0.51
Turtle Reef	0.47	0.84	0.96	0.65	1.00	1.00	0.29	0.74	0.94
Whale Reef	0.06	0.86	0.67	0.40	1.00	0.76	0.52	0.61	0.77

STEP 6: Once we have calculated final resilience scores, we can rank the sites from highest to lowest resilience score. In Excel, we can rank the sites by sorting the data table to present the value for anchored resilience scores from largest to smallest. We then insert a new column called "Ranking" and number the sites sequentially. In the completed table shown on the next page, you can see that the site with the highest anchored resilience score, Coral Reef, has a ranking of 1 and the site with the lowest anchored resilience score, Sea Fan Reef, has the lowest ranking (18).

STEP 6: Ranking sites

Site	Ranking	R Score_Anchored	Resilience Score	Resistant Coral Species	Temp Variability	Coral Diversity	Herbivore Biomass	Coral Disease	Macroalgae Cover	Coral Cover
Coral Reef	1	1.00	0.79	0.74	0.86	0.89	0.60	1.00	0.97	0.48
Turtle Reef	2	0.94	0.74	0.47	0.84	0.96	0.65	1.00	1.00	0.29
Shark Reef	3	0.90	0.71	0.28	0.76	1.00	0.63	0.99	0.91	0.44
Ray Reef	4	0.89	0.70	0.46	0.87	0.91	0.57	1.00	1.00	0.10
Clam Reef	5	0.84	0.67	0.97	0.94	0.55	0.10	1.00	0.98	0.12
Sponge Reef	6	0.83	0.66	0.96	0.97	0.60	0.20	1.00	0.89	0.00
Fish Reef	7	0.81	0.64	0.74	0.76	0.64	0.07	1.00	0.99	0.26
Whale Reef	8	0.77	0.61	0.06	0.86	0.67	0.40	1.00	0.76	0.52
Dolphin Reef	9	0.74	0.59	0.51	0.76	0.80	0.18	1.00	0.81	0.06
Octopus Reef	10	0.70	0.56	1.00	0.91	0.00	0.00	1.00	0.93	0.05
Nudibranch Reef	11	0.68	0.53	0.08	0.85	0.66	0.08	1.00	1.00	0.07
Prawn Reef	12	0.68	0.53	0.21	0.94	0.86	0.00	1.00	0.15	0.57
Nautilus Reef	13	0.64	0.51	0.15	0.94	0.67	0.01	0.85	0.78	0.13
Crab Reef	14	0.59	0.46	0.00	0.76	0.00	0.01	1.00	0.98	0.48
Lobster Reef	15	0.55	0.43	0.32	0.94	0.64	0.28	0.00	0.65	0.20
Starfish Reef	16	0.51	0.40	0.00	0.94	0.00	0.03	1.00	0.76	0.07
Sea Cucumber Reef	17	0.49	0.39	0.00	0.81	0.00	0.02	1.00	0.87	0.00
Sea Fan Reef	18	0.37	0.29	0.00	0.89	0.00	0.00	1.00	0.00	0.15

STEP 7: The resilience analysis results may be easier to interpret if you bin the anchored resilience scores into 3 categories: high, medium or low. Based on resilience assessments conducted in Micronesia and the Caribbean, the following data ranges for final resilience score were used for each bin: 0.8-1.0 for high, 0.6-0.79 for medium and <0.6 for low. High (green), medium (yellow) and low (red) resilience scores are shown in the table on the next page.

STEP 7: Grading sites as having high, medium or low relative resilience

Site	Ranking	R Score_Anchored	Resilience Score	Resistant Coral Species	Temp Variability	Coral Diversity	Herbivore Biomass	Coral Disease	Macroalgae Cover	Coral Cover
Coral Reef	1	1.00	0.79	0.74	0.86	0.89	0.60	1.00	0.97	0.48
Turtle Reef	2	0.94	0.74	0.47	0.84	0.96	0.65	1.00	1.00	0.29
Shark Reef	3	0.90	0.71	0.28	0.76	1.00	0.63	0.99	0.91	0.44
Ray Reef	4	0.89	0.70	0.46	0.87	0.91	0.57	1.00	1.00	0.10
Clam Reef	5	0.84	0.67	0.97	0.94	0.55	0.10	1.00	0.98	0.12
Sponge Reef	6	0.83	0.66	0.96	0.97	0.60	0.20	1.00	0.89	0.00
Fish Reef	7	0.81	0.64	0.74	0.76	0.64	0.07	1.00	0.99	0.26
Whale Reef	8	0.77	0.61	0.06	0.86	0.67	0.40	1.00	0.76	0.52
Dolphin Reef	9	0.74	0.59	0.51	0.76	0.80	0.18	1.00	0.81	0.06
Octopus Reef	10	0.70	0.56	1.00	0.91	0.00	0.00	1.00	0.93	0.05
Nudibranch Reef	11	0.68	0.53	0.08	0.85	0.66	0.08	1.00	1.00	0.07
Prawn Reef	12	0.68	0.53	0.21	0.94	0.86	0.00	1.00	0.15	0.57
Nautilus Reef	13	0.64	0.51	0.15	0.94	0.67	0.01	0.85	0.78	0.13
Crab Reef	14	0.59	0.46	0.00	0.76	0.00	0.01	1.00	0.98	0.48
Lobster Reef	15	0.55	0.43	0.32	0.94	0.64	0.28	0.00	0.65	0.20
Starfish Reef	16	0.51	0.40	0.00	0.94	0.00	0.03	1.00	0.76	0.07
Sea Cucumber Reef	17	0.49	0.39	0.00	0.81	0.00	0.02	1.00	0.87	0.00
Sea Fan Reef	18	0.37	0.29	0.00	0.89	0.00	0.00	1.00	0.00	0.15

STEP 8: Stress on reefs related to human activity can be assessed in the same way as the analysis of relative resilience presented on the preceding pages. Here, four main anthropogenic impacts are shown: nutrients, sedimentation, anchoring and fishing pressure. Scores for each of these stressors for each site have been anchored to the maximum value, so all values now have a standard 0 to 1 scale. The "stress score" is the average of the scores for each of the four stressors calculated for each site. Then, the stress scores are anchored to the maximum score, meaning we can express stress related to human activity at each site as relative to the location where this stress is most severe. High scores mean high stress, so now the high category is negative rather than positive, so high stress is shown in red, medium in yellow and low stress is shown in green.

STEP 8: Assessing anthropogenic stress

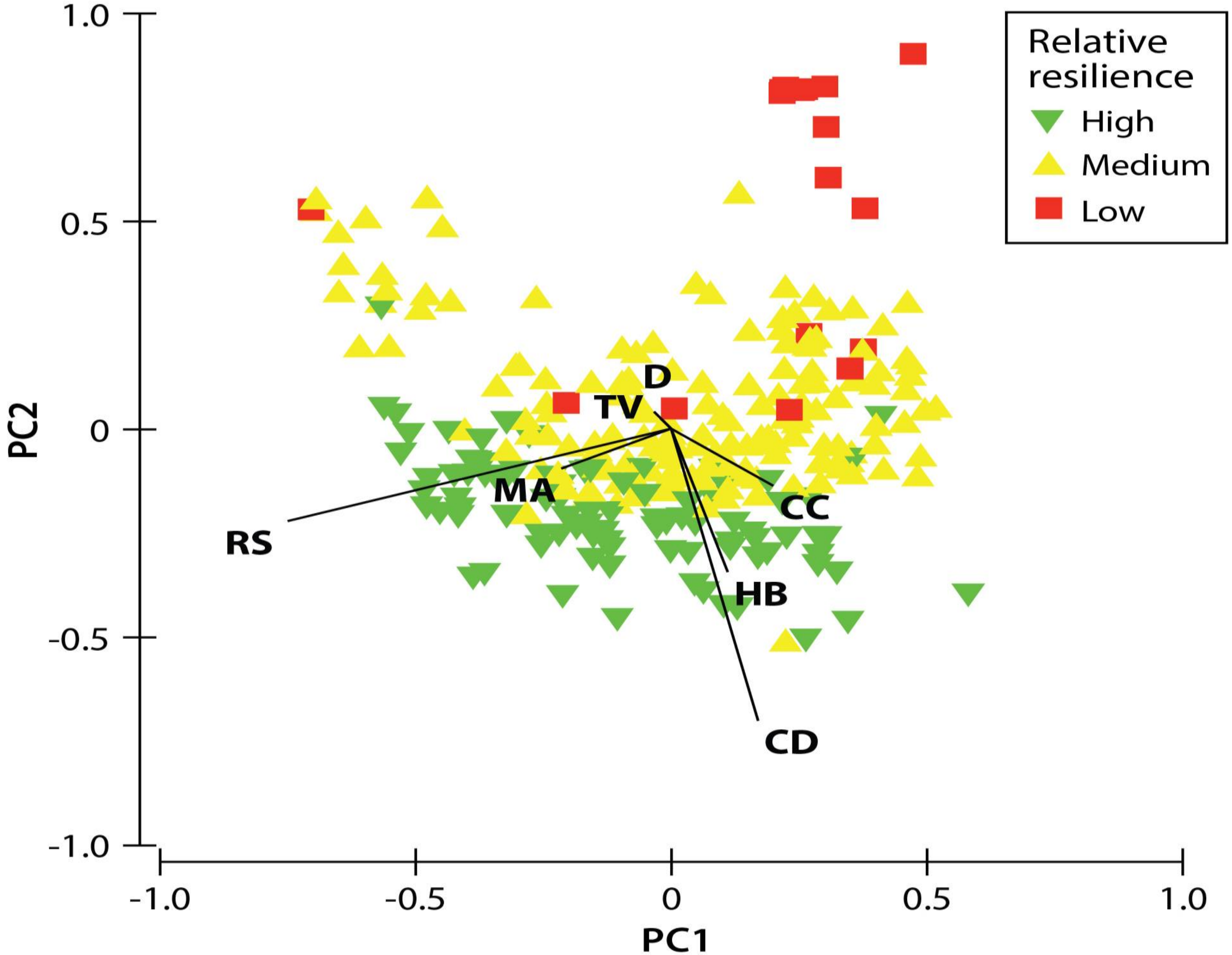
Site	Stress Score Anchored	Stress Score	Nutrients	Sedimentation	Anchoring	Fishing Pressure
Nudibranch Reef	1.00	0.86	0.74	0.88	0.89	0.93
Prawn Reef	0.96	0.82	0.47	0.87	0.96	0.99
Shark Reef	0.91	0.79	0.46	0.90	0.91	0.87
Starfish Reef	0.83	0.72	0.96	1.00	0.60	0.31
Nautilus Reef	0.88	0.75	0.28	0.78	1.00	0.96
Lobster Reef	0.77	0.66	0.97	0.97	0.55	0.15
Coral Reef	0.69	0.59	0.51	0.78	0.80	0.28
Sea Cucumber Reef	0.66	0.57	0.74	0.78	0.64	0.10
Fish Reef	0.68	0.59	0.32	0.97	0.64	0.43
Ray Reef	0.59	0.51	0.21	0.97	0.86	0.01
Sea Fan Reef	0.65	0.56	0.06	0.88	0.67	0.62
Turtle Reef	0.56	0.49	1.00	0.94	0.00	0.00
Clam Reef	0.53	0.45	0.15	0.97	0.67	0.02
Whale Reef	0.30	0.26	0.00	0.97	0.00	0.05
Octopus Reef	0.27	0.23	0.00	0.92	0.00	0.00
Dolphin Reef	0.25	0.22	0.00	0.84	0.00	0.04
Sponge Reef	0.23	0.20	0.00	0.78	0.00	0.02
Crab Reef	0.23	0.20	0.00	0.78	0.00	0.02

Presenting and interpreting the analysis results:

STEP 1: In addition to assessing the relative resilience of their sites, managers may want to determine whether differences in resilience scores are consistently driven by a certain resilience indicator or suite of indicators. A Principle Components Analysis (PCA) is a statistical analysis that can be used to determine commonalities and differences among the scores for resilience indicators. It can also determine which of the resilience indicators are the strongest drivers of differences in the resilience score.

The PCA shown on the next page is from an analysis of relative resilience for coral reef sites near St. Croix in the US Virgin Islands (see case study). Here, the horizontal axis, PC1, was responsible for 32.8% of the variation, with PCA eigenvector values indicating that Resistant Species (RS=0.902) is a major driver of the differences among sites in the final resilience scores. This indicator ranges across medium and highly resilient sites; but nearly all of the sites assessed as having low relative resilience scores, have a low value for resistant species. The vertical axis, PC2, was responsible for 23.8% of the variation, with PCA eigenvector values indicating that Coral Diversity (CD=-0.845) and Herbivore Biomass (HB=-0.414) are also major drivers of the differences among sites in final resilience scores. There is a very strong gradient of resilience scores across the vertical axis indicating that increasingly higher coral diversity and herbivore biomass are always associated with higher resilience scores.

STEP 1: Using statistics to determine which indicators drive differences among sites

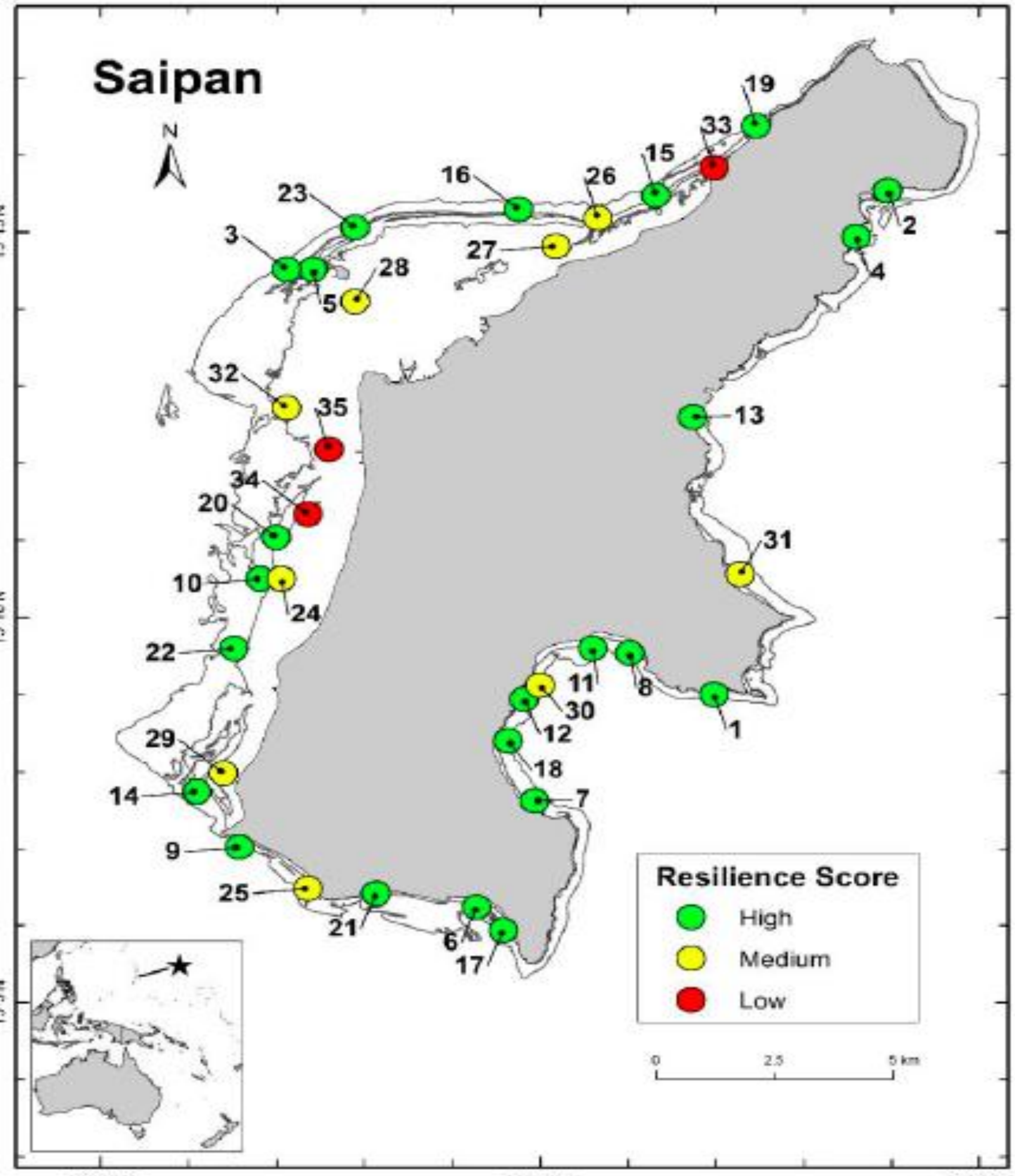


STEP 2: There are several presentation formats that may be useful for presenting the results of a resilience assessment. Rankings can be presented using a table or spatially on maps that distinguish high, medium and low resilience sites using colors (e.g., green, yellow and red). The examples on the next page are from a resilience analysis for reef sites near Saipan in the Commonwealth of the Northern Mariana Islands (see case study).

STEP 2: Presenting resilience analysis results

Resilience Score:
- = High (green)
- = Medium (yellow)
- = Low (red)

Site Names	Rank	Anchored Resilience Score	Resilience Score	Coral Diversity	Recruitment	Bleaching Resistance	Temperature variability	Herbivore biomass	Macroalgae cover*
Forbidden Island	1	1.00	0.84	0.96	0.68	0.73	0.97	0.59	1.00
Bird Island	2	0.99	0.83	0.98	0.41	0.68	0.99	1.00	1.00
Lanyas	3	0.98	0.82	0.98	0.77	0.67	0.97	0.35	1.00
Nanasu Reef	4	0.95	0.80	0.95	0.52	0.61	1.00	0.90	0.92
MMT - Managaha MPA	5	0.94	0.79	0.82	0.53	0.81	0.97	0.44	0.87
Obyan Beach	6	0.90	0.76	0.98	0.94	0.67	0.96	0.79	1.00
South Laolao	7	0.90	0.76	0.99	0.73	0.84	0.96	0.14	0.66
Laolao Bay East	8	0.89	0.75	0.96	1.00	0.92	0.97	0.37	0.99
Agingan Point	9	0.86	0.72	0.94	0.94	0.76	0.98	0.20	1.00
Oleai Rocks	10	0.86	0.72	0.96	0.75	0.66	0.95	0.44	1.00
Laolao Bay Mids	11	0.85	0.72	0.95	0.59	0.72	0.97	0.60	0.99
North Dakota	12	0.85	0.71	0.98	0.72	0.73	0.97	0.20	1.00
Old Man By the Sea	13	0.84	0.71	0.97	0.33	0.79	0.95	0.38	0.92
Point Break Reef	14	0.84	0.71	0.95	0.76	0.70	0.96	0.27	1.00
Pau Pau	15	0.84	0.71	0.97	0.77	0.61	0.97	0.32	1.00
Achu Dangkulu	16	0.84	0.70	0.98	0.62	0.77	0.97	0.09	1.00
Boy Scout	17	0.83	0.70	0.98	0.70	0.80	0.96	0.36	1.00
South Dakota	18	0.82	0.69	0.98	0.34	0.92	0.96	0.15	0.54
Wing Beach	19	0.82	0.69	0.98	0.76	0.57	0.99	0.17	1.00
Lighthouse Reef	20	0.82	0.69	0.99	0.45	0.81	0.95	0.31	1.00
Ladder Beach	21	0.82	0.69	1.00	0.71	0.61	0.96	0.14	1.00
MMT - Outside Grand Hotel	22	0.82	0.68	0.98	0.48	0.79	0.96	0.23	1.00
Elbow Reef	23	0.82	0.68	1.00	0.47	0.71	0.97	0.11	1.00
Oleai Staghorn	24	0.79	0.66	0.72	0.17	1.00	0.95	0.62	0.84
Coral Ocean Point	25	0.77	0.65	1.00	0.66	0.58	0.96	0.20	1.00
Achugao	26	0.77	0.65	0.97	0.63	0.45	0.96	0.08	1.00
Tanapag Staghorn	27	0.72	0.60	0.80	0.34	0.93	0.97	0.24	0.85
MMT - Managaha Patch Reef	28	0.71	0.60	0.95	0.36	0.73	0.96	0.40	0.94
Pak Pak Beach	29	0.70	0.59	0.93	0.24	0.51	0.96	0.04	0.96
Tuturam	30	0.70	0.58	0.98	0.59	0.82	0.96	0.13	0.00
Tank Beach	31	0.69	0.58	0.99	0.43	0.78	0.96	0.08	1.00
Peysonnelia Reef	32	0.66	0.55	0.82	0.60	0.97	0.95	0.14	1.00
Marianas Resort	33	0.57	0.48	0.45	0.07	0.23	0.97	0.26	0.69
Quartermaster Staghorn	34	0.53	0.44	0.10	0.07	0.23	0.95	0.42	0.55
Fishing Base Staghorn	35	0.49	0.41	0.00	0.00	0.00	0.96	0.13	1.00



STEP 3: Analyzing relative resilience can inform a range of different management actions, especially when the resilience assessment is combined with an assessment of anthropogenic stress. Here are several examples of the kinds of actions that could be taken to support the resilience of the reef system based on our example on the next page:

1. Sites with high resilience, like Coral, Turtle and Shark Reef, that are not already included in an MPA network represent conservation priorities. These are 'critical areas' that need to be considered when designing MPA networks.
2. Here, scores for sedimentation are higher (meaning high stress –red cells) than scores for the other three stressors. Sedimentation is affecting many sites in our reef system and coastal zone management planning and actions that reduce sedimentation will support resilience at the greatest number of reef sites.
3. There are high and medium resilience sites ("Ranking" column; green and yellow cells, respectively) with high levels of anthropogenic stress ("Stress Score Anchored" column; red cells). At four reefs: Shark, Nudibranch, Prawn and Nautilus Reef, anchoring stress is high. You can see in the table that in our example, the anchoring is likely caused by fishers as the fishing pressure is also high at these four sites. Managers could consider approaches to influence the way fishers anchor at these sites. For example, anchoring can be managed at the local-scale by creating no-anchoring areas, installing mooring buoys, and/or through communication and engagement. The results for sites you are managing may be very different from those presented here; the point is that resilience analysis can identify local-scale actions for stressors we can influence at high and medium resilience sites.
4. A PCA analysis can be useful because the resilience indicators that most greatly influence rankings should be a part of any ongoing monitoring, if they are not already.

STEP 3: Interpreting analysis results to inform management

Site	Ranking	R Score_Anchored	Stress Score Anchored	Stress Score	Nutrients	Sedimentation	Anchoring	Fishing Pressure
Coral Reef	1	0.97	0.77	0.59	0.51	0.78	0.80	0.28
Turtle Reef	2	0.80	0.63	0.49	1.00	0.94	0.00	0.00
Shark Reef	3	1.29	1.02	0.79	0.46	0.90	0.91	0.87
Ray Reef	4	0.84	0.66	0.51	0.21	0.97	0.86	0.01
Clam Reef	5	0.74	0.59	0.45	0.15	0.97	0.67	0.02
Sponge Reef	6	0.33	0.26	0.20	0.00	0.78	0.00	0.02
Fish Reef	7	0.96	0.76	0.59	0.32	0.97	0.64	0.43
Whale Reef	8	0.42	0.33	0.26	0.00	0.97	0.00	0.05
Dolphin Reef	9	0.36	0.28	0.22	0.00	0.84	0.00	0.04
Octopus Reef	10	0.38	0.30	0.23	0.00	0.92	0.00	0.00
Nudibranch Reef	11	1.42	1.12	0.86	0.74	0.88	0.89	0.93
Prawn Reef	12	1.35	1.07	0.82	0.47	0.87	0.96	0.99
Nautilus Reef	13	1.24	0.98	0.75	0.28	0.78	1.00	0.96
Crab Reef	14	0.33	0.26	0.20	0.00	0.78	0.00	0.02
Lobster Reef	15	1.08	0.86	0.66	0.97	0.97	0.55	0.15
Starfish Reef	16	1.18	0.93	0.72	0.96	1.00	0.60	0.31
Sea Cucumber Reef	17	0.93	0.74	0.57	0.74	0.78	0.64	0.10
Sea Fan Reef	18	0.92	0.72	0.56	0.06	0.88	0.67	0.62