Primer for Ecosystem Thresholds Analysis

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Note: these specific thresholds are appropriate for the Indian Ocean, Indonesia, and Soloman Islands. They may not be applicable in other regions. Meta-analysis of coral reef status metrics and fishable biomass should be conducted to identify whether thresholds exist and if so, at what levels of fishable biomass.

Summary

* Sustainably managing ecosystems is challenging, especially for complex systems such as coral reefs. This document provides guidance to develop critical reference points for sustainable management by using associations between levels of target fish biomass (as an indicator of fishing intensity) and metrics of ecosystem state in coral reefs.
* Metrics of ecosystem state are; coral cover, macroalgal cover, and the ratio between coral and macroalgal cover, as well as measurements of organisms such as fish biomass and species richness, urchin biomass, and rate of predation on urchins.
* Data on ecological metrics area collected across different management systems, from marine reserves, areas with restricted gear fishing, and areas open to all forms of fishing.
* Plot metrics against a gradient of fishable biomass to get an idea of how much fish could be exploited while maintaining a stable ecosystem.
* Develop an tangible system to evaluation target sites across management systems, by 1) define an estimate of unfished biomass, 2) and levels of biomass in which fisheries closures and, less frequent fishing, gear restrictions should be implemented.
* Preliminary analysis in the Indian Ocean provides guidance for monitoring and managing stocks;
  + If fish density > 1130 kg/ha fish biomass may be close to unfished levels and the system is likely to be healthy and resilient. Maintain status quo.
  + If fish density < 850 kg/ha, the coral reef system may be near the threshold of a state change to a healthy state that is being fished down, and perhaps somewhat less resilient. Assess stocks, adopt fishing mortality control strategy.
  + If fish density is close to 640 kg/ha, the coral reef system may be producing pretty good yield (80-100% of MSY) but is need of strong management to maintain healthy stocks and a healthy coral reef system. Assess stocks, adopt fishing mortality control strategy.
  + If fish density < 500 kg/ha, the coral reef system may have crossed a threshold to an unhealthy state that it can recover from if fishing is restricted. Assess stocks, adopt rebuilding strategy.
  + If fish density < 300 kg/ha, the coral reef system is likely to have shifted to an unhealthy state from which recovery is very difficult and fish stocks may be in an overfished condition. Active ecosystem restoration may also be required, as this threshold may be associated with increased resilience of the unhealthy state.
  + If fish density is between 300 and 500 kg/ha, conduct rapid reef assessment using timed surveys, use ecological insight to determine which groups of species to focus on when system is between 300 and 500 kg/ha; focus harvest on species with low vulnerability scores unless they are important ecological engineers.
* These findings provide adaptive management strategies for multispecies coral reef fisheries and highlight key tradeoffs required to achieve different fisheries and conservation goals

Introduction

One of the most important and fundamental goals of managing ecosystems is to conserve a sufficient representation of targeted habitats and associated species. These goals make sustainably managing ecosystems a challenge, especially for complex systems such as coral reefs. For example, coral reefs have proven difficult to successfully manage, to some extent, because of the diversity and associated interactions of species involved, and the relationship between the observed responses in the system and the time frame a system response is manifested (Hughes et al. 2010, McClanahan et al 2011). Changes in metrics of ecosystem health are revealed at variable times scale, therefore, some metrics might be appropriate for monitoring and managing an ecosystem before it is degraded and approaching a collapse (Fig. 1, Table 1-2). For example, the work carried out by McClanahan et al. 2011, demonstrates threshold values of ecosystem metrics along a gradient of fishable biomass (FB), indicating the threshold of ecological metrics that serve as early warning signals, > 0.5 BMMSY can result in a healthy system and < 0.5 BMMSY can result in an ecosystem phase shift or collapse (Fig. 1). The question managers and practitioners to clarify is what are the critical metrics to observe for managing a sustainable ecosystem and what are the critical thresholds for these metrics? This document provides guidance to develop critical reference points for sustainable management by using associations between levels of target fish biomass (as an indicator of fishing intensity) and metrics of ecosystem state.



Figure 1. State of eight ecological indicator metrics among closed (red circles), fishing-restricted (orange triangles), and unregulated (green circles) locations along a gradient of fishable biomass for reefs in the Indian Ocean. (A) Percentage cover of macroalgae; (B) ratio of macroalgae to coral; (C) urchin predation index; (D) numbers of fish species; (E) proportion of herbivorous fish in total fishable biomass; (F) urchin biomass (kg/ha); (G) percentage cover of calcifying substrates; (H) percentage cover of hard coral. Blue lines represent the best-fit model, based on DIC (Methods), and solid black lines indicate the thresholds (with 95% confidence intervals as dotted black lines) predicted by the Bayesian models. *Taken from McClanahan et al 2011*.

Methods

We have adopted the approach developed by McClanahan et al. (2011), which utilizes fishery independent underwater visual surveys to measure and assess metrics of ecosystem health by developing critical reference points (thresholds) of ecosystem shifts (Table 1). These techniques can be integrated into data collection from fishing surveys or logbooks. We will briefly go over techniques to collect data, interpret data and how to conduct a threshold analysis of coral reef status metrics and fishable biomass if the target region does not fall within the Indian Ocean, Indonesia, or Soloman Islands.

1. Preliminary Assessment of Ecosystem Status Using Fishing data
2. Conduct random fishing transects or collect logbooks
   1. If fishers are amendable to fishing along a transect, have the fishers record per fishing sites; if visiting more than one site per fishing trip
      1. Number of fish species,
      2. Number of fish caught, and general size-frequency
      3. Number of herbivorous fish
      4. Areas (ha) of fishing effort
      5. Total biomass of catch
3. Conduct fishery independent sampling with management zones (i.e. historic low fishing, no fishing, etc.) to determine B0
4. Estimate total fishable biomass, fish species richness, percentage of herbivores in the catch across fishing sample
   1. Standardize estimate to area of fishing effort
5. If in Indian Ocean, Indonesia, or Soloman Islands, ompare estimates of total fishable biomass to estimates of B0, 0.5 B0 and 0.25 Bo to empirically derived estimates of ecosystem metrics in the Indian Ocean (IV. ESTIMATES OF THRESHOLDS FOR ECOLOGICAL METRICS AND FISHABLE BIOMASS)
6. If not in the Indian Ocean, Indonesia, or Soloman Islands go to III. META-ANALYSIS OF CORAL REEF STATUS METRICS AND FISHABLE BIOMASS, to conduct a meta-analysis with your target region.
7. Preliminary Assessment of Ecosystem Status with Fishery Independent data
8. Conduct / use existing underwater visual surveys
   1. Using underwater visual surveys techniques the abundance and size of all diurnally active, noncryptic, reef-associated fishes are quantified at each site and across management types.
   2. Survey sites are selected using a stratified-random sampling design whereby sites were randomly located through the reef system and across management types.
   3. The sampling strategy provides a spatially comprehensive and unbiased set of size frequency distributions of fish across a wide range of habitat types.
   4. Fish surveys were conducted within a 30 m long and 2 m wide (120 m2) or 4x50m belt transects deployed along a randomly selected bearing (0–360u). All individuals are identified to species level where possible and body lengths (total length) were visually estimated (Marks 2007, McField 2009).
   5. Observers should avoided double counting by surveying larger mobile species first and disregarding individuals that left the survey boundary and then reentered

Table 1. Ecological metrics and processes represented by each metric, and units of analysis



2. Calculate unfished reef biomass (**B0**)

* 1. **BO**(unfished reef biomass) is calculated from fish surveys in marine protected areas and unfished reefs.
  2. Under an ideal scenario, estimates of Bo are from managed areas that have been in place over 15 years and larger than 5 km2.
  3. BO is used to calculate **BMMSY**, or the biomass that allows for maximum sustainable yield from the community (multi-species MSY).
  4. Multi-species BMMSY, instead of a single value, a range based on population growth models are used for BMMSY.
  5. The max rate of change is at half the leveling value (0.5 BO ).
  6. Lower limit was set to 0.25BO to represent populations with exponential saturation behavior. This range was used to determine where a MMSY would lie in relation to ecological switch points (McClanahan et al. 2011 Figure 2 A&B).

1. Compare estimates of B0, 0.5 B0 and 0.25 Bo to empirically derived estimates of ecosystem metrics in the Indian Ocean.(IV. ESTIMATES OF THRESHOLDS FOR ECOLOGICAL METRICS AND FISHABLE BIOMASS)
2. If not in the Indian Ocean, Indonesia, or Soloman Islands go to III. META-ANALYSIS OF CORAL REEF STATUS METRICS AND FISHABLE BIOMASS, to conduct a meta-analysis with your target region.

III. Meta-analysis of coral reef status metrics and fishable biomass

1. Calculate ecosystem metrics that are indicative of key reef states and processes
   1. Summarize ecological metrics (Table 1), in order to carry out analysis
   2. Standardized metrics by area surveyed and used for the calculation of total biomass (ha), herbivorous fish biomass, sea urchin predator biomass, and fish species richness.
   3. Biomass estimates: based up life history attributes, use fish-length data to calculate length– weight relationships for species or families (Froese and Pauly 2008)
2. Data Analysis
   1. Normalize ecosystem metrics using standard tests and transformation of data for normal distributions
      1. To remove right skewness typically the square root, cube root, logarithm, or reciprocal of a the variable
      2. To remove left skewness raise the variable to a power greater than 1, such as squaring or cubing the values
   2. Use switch-point analysis to model estimates change in the ecosystem metrics.
      1. Switch-point models assess if variance thresholds exists for the ecological metrics along a gradient of fishable biomass
      2. Common tools (Table 3) used for switch point analysis are: linear (e.g.piecewise-linear regression, broken stick models) and Bayesian (e.g., change point, strucchange, SiZer, etc.)
3. Estimates of Thresholds for Ecological Metrics and Fishable Biomass

These specific thresholds are appropriate for the Indian Ocean, Indonesia, and Soloman Islands. They may not be applicable in other regions. Meta-analysis of coral reef status metrics and fishable biomass should be conducted to identify whether thresholds exist and if so, at what levels of fishable biomass.

* 1. If fish density > 1130 kg/ha fish biomass, biomass is similar to unfished levels and the system is likely to be healthy and resilient. Maintain status quo.
  2. If fish density < 850 kg/ha, the coral reef system may be near the threshold of a state change to a healthy state that is being fished down, and perhaps somewhat less resilient. Assess stocks, adopt fishing mortality control strategy.
  3. If fish density is close to 640 kg/ha, the coral reef system may be producing pretty good yield (80-100% of MSY) but is need of strong management to maintain healthy stocks and a healthy coral reef system. Assess stocks, adopt fishing mortality control strategy.
  4. If fish density < 500 kg/ha, the coral reef system may have crossed a threshold to an unhealthy state that it can recover from if fishing is restricted. Assess stocks, adopt rebuilding strategy.
  5. If fish density < 300 kg/ha, the coral reef system is likely to have shifted to an unhealthy state from which recovery is very difficult and fish stocks may be in an overfished condition. Active ecosystem restoration may also be required, as this threshold may be associated with increased resilience of the unhealthy state.
  6. If fish density is between 300 and 500 kg/ha, conduct rapid reef assessment using timed surveys, use ecological insight to determine which groups of species to focus on when system is between 300 and 500 kg/ha; focus harvest on species with low vulnerability scores unless they are important ecological engineers.

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Table 2. Key terms and definitions for assessing ecosystem thresholds for state changes.

Table 3. Models and tools available to assess critical thresholds in complex ecosystems

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **MODEL** |  | **DESCRIPTION** | | | | | | |
| Breakpoint regression (*piecewise regression*) |  | Statistical determination if 2 relationships (usually linear) fit data better than one; also called piecewise regression | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Cumulative frequency distribution |  | Detects changes in expected distributions, can be combined with analytical methods to determine differences among distributions (e.g., D1) and acceptable levels of change (e.g., T95) | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Nonlinear curve fitting |  | Search methods used to fit a user-defined equation | | | | | |  |
|  |  |  |  |  |  |  |  |  |
| Nonparametric changepoint analysis |  | A test for change in variance, closely related to 2-dimensional Kolmogorov–Smirnov test; adapted to calculate empirical confidence intervals | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Quantile regression |  | Characterization of changes in variance; includes quantile regression trees and quantile regression splines | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Recursive partitioning (*regression tree*) |  | Predictors can be categorical or continuous; response can be univariate (classification and regression tree [CART]) or multivariate (multivariate regression tree [MRT]); referred to as regression tree analysis | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Regime shift detection |  | Find shifts in temporal data series | | | |  |  |  |
|  |  |  |  |  |  |  |  |  |
| Significant zero crossings (*SiZer*) |  | Derivative-based nonparametric approach using a smoothing function | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Threshold Indicator Taxa Analysis (*TITAN*) |  | Indicates changes in community structure across a gradient, a form of nonparametric changepoint analysis combined with indicator species analysis | | | | | | |
|  |  |  |  |  |  |  |  |  |
| Two-dimensional Kolmogorov–Smirnov test |  | A nonparametric test for changes in variance; predicts a threshold in the driver and the response variable | | | | | | |