A proposed framework for a national coral reef assessment program

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The Philippines has limited up-to-date information on the current condition of its coral reefs and how this has changed over the last few decades. This comes at a time when threats to corals and coral reefs in general, and our economic and social dependence on them are at their greatest. This document outlines a framework by which a national coral reef assessment can be designed and this hopefully serves as a basis for stimulating urgently needed discussions on precisely how such an assessment could be undertaken. We propose that we should aim for an outcome of the national assessment that goes beyond generating updated information and that moves us to improving the conservation and management of Philippine coral reefs. We further suggest that the objectives of the assessment must first be precisely defined and agreed upon since the sampling design and corresponding costs of the assessment will depend greatly on these. We propose that the assessment should not be limited to estimating the amount of living coral and reef fish left in our reefs, but should also include an assessment of the health of the associated seagrass and even mangrove habitats that operate together with coral reefs in providing the coastal ecosystem services our people derive benefit from. The metrics to quantify the health of the coral reef communities and associated coastal habitats should be carefully selected as well as the assessment units, the sampling strata, and the methodologies involved in such an effort.

INTRODUCTION

Despite the pioneering assessment efforts in the late 1970s by Gomez et al. (1981), the Philippines at present has little synoptic information on the current condition of its coral reefs and how this has changed over the last few decades. This comes at a time when threats to corals and coral reefs in general, and our economic and social dependence on them are at their greatest. The limited information available however suggests one third of reef-building coral species are under elevated threat of extinction due to human impacts and climate change (Carpenter et al. 2008). The Philippines' large population sizes living near coral reefs, their food consumption and livelihood patterns, and the small proportion of reefs under protective management all further contribute to the high vulnerability of the country to the loss of coral reefs (Burke et al. 2011).

Fortunately there are initiatives, in both the Department of Environment and Natural Resources (DENR) and the Department of Science and Technology (DOST), to undertake a nationwide assessment of coral reefs. This document outlines a framework by which a national coral reef assessment can be designed. This hopefully serves as a basis for the scope of urgently needed discussions on precisely how such an assessment could be undertaken.

We argue that we should aim for an outcome of the national assessment that goes beyond generating updated information and that moves us to improving the conservation and management of Philippine coral reefs. We further argue that the objectives of the assessment must first be precisely defined and agreed upon since the choice of assessment units, the sampling design, and corresponding costs of the assessment will depend greatly on these. We propose that the assessment should not be limited to estimating the amount of living coral and reef fish left in our reefs but also include, when appropriate, the health of the associated

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seagrass and even mangrove habitats that operate together with coral reefs in providing the coastal ecosystem services our people derive benefit from. The metrics to quantify the health of the coral communities and associated coastal habitats should be carefully selected. Further, we need to undertake resilience and risk assessments to serve as basis for an analysis of human-induced and natural threats (e.g., that of coral bleaching, coral diseases) to our reefs and prognosis for their future. This allows for more than static descriptors of reef health. A monitoring system must also be established soon after the assessment and this system should be centered on select sentinel sites operated by front-line local agencies backed up by local academic institutions. Capacity and capability to undertake these assessments and monitoring must be built at various levels in the relevant national and local government organizations, and the local academic institutions that feed these organizations with trained personnel. Finally, the quality of data from the assessment and the monitoring should be maintained by strict interoperability standards, and continuous training and retraining should be undertaken to expand and upgrade the work force needed for this national assessment effort.

On the metrics of habitat health

The Philippines, in the 1970s, was among the first countries to undertake a systematic inventory of its coral reefs. Conducted over seven years, the "Investigation of the Coral Resources of the Philippines (ICRP)" program produced the quartile benchmark standard (poor: 0-24.9%, fair: 25-49.9%, good: 50-74.9%, excellent: 75-100% cover) that is still in use today. It is to be noted, however, that the category "coral" included both hard and soft coral. ICRP also revealed that only about 5% of the country's reefs were in excellent condition then (Gomez et al. 1981). Such a national level inventory has never been repeated since all subsequent projects focused only on particular sections of the country. However, the use of ICRP as a benchmark involves a number of limitations. Gomez et al. (1994a; see also Gomez et al. 1994b) reviewed reef research in the country until then and pointed out that ICRP findings cannot be compared with data from the ASEAN-Australia Living Coastal Resources (LCR) Project and subsequent data. For example, they pointed out that "…the ICRP Project contributed little to the understanding of the major controls of coral distribution" and that "…ICRP studies were not extended to include monitoring of the reefs surveyed." They also added that "…coral cover is not always a reliable measure of reef health."

Ideally, the metrics for the national assessment to be chosen should have the following characteristics (after Jameson et al. 1998):

- They should quantify the ecological integrity of coral reef ecosystems in the Philippines
- They should be sensitive, scientifically sound, and reflect the best-attainable conditions at a given area
- They should be relatively easy and cost-effective to measure
- They should incorporate management and regulatory goals (e.g., consideration of multiple uses, adherence to local laws and international commitments) to help protect important, natural assemblages
- They should be defensible in a court of law.

Assessment of hard coral cover seems a necessary and critical metric in the national reef assessment, but this must be clearly complemented with measures of other benthic cover such as that of soft coral, sponges and other benthic invertebrates, micro- and macro-algae, unconsolidated substrate such as sand and silt, and consolidated substrate such as bare rock or standing dead coral. Together these quantify the abundance of the framework-building coral and the amount of habitat space potentially available to them. Measures of biodiversity (e.g., coral generic diversity with corresponding genus-area curves per sampling unit), coral health (e.g., density of coral colonies without lesions due to predators, diseases), and demography (e.g., size structure of select species) are also needed. Considerable headway has also been achieved in showing the importance of marine protected areas in showing their significance to recovery and biomass buildup of their associated fish communities (Alcala and Russ 1990, Russ and Alcala 1996, Russ et al. 2004) although their significance to the reef benthic communities have only been recently alluded to (Magdaong et al. 2014).

The choice of metrics is critical since this will impact the sampling design, the amount of financial and human resources required, and the time needed to adequately assess the reefs and associated habitats. Measures of water quality such as water transparency or total suspended solids, spatial extent and density of seaweed and seagrass, abundance and diversity of associated fishes, and various measures of human activity are also necessary. These metrics allow for inferences on the drivers affecting the critical metrics. Note that the aforementioned "less critical" metrics are only labelled as such because these are not associated with the primary objective of determining the current status of reefs in the country, but are critical for a secondary objective of determining likely drivers or determinants of the current status of coral reefs, or a different objective such as the assessment of impacts of marine protected areas on reef health.

On the mapping of reef assessment units

Ideally, a national coral reef assessment program involves the generation of precise, accurate measures such as the proportion of reefs belonging to a certain coral cover category, or better yet, the average and standard error of hard coral cover in the reefs of the country, and management-relevant sections thereof. This requires (in addition to the metrics) that the assessment units and the scope of the assessment also be decided on early in the implementation of the program. As an example, the assess-

ment unit could be a coral reef area with a geological structure that extends at least 10m from the shore (i.e., in width), at least 200m long, with a reef slope coral community extending to at least 6m deep. This unit should have a seagrass meadow in the reef flat but may or may not have mangroves along its immediate shore. For simplicity, though, the assessment unit could initially just be hard substrate areas within a given depth range that are not necessarily true coral reefs in the geologic sense.

The definition of the assessment units would be crucial in enhancing the value of the national assessment and justifying its expense long after its completion. Ideally, more precise, locally relevant standards or benchmarks of reef health are set and maintained through management schemes involving the designation of selected assessment units as reference or benchmark reefs, and water- and resource-use zoning and regulations. Thus the extent and boundaries of important reef and associated assemblages, both impaired/damaged and unimpaired/pristine, will need to be mapped, labelled, and disseminated before the assessment. Technologies developed and being refined by the Department of Science and Technology (DOST)-sponsored Automated Rapid Reef Assessment System (ARRAS) Program and its successor, the Coral Reef Assessment Visualization and Advanced Tools (CRAVAT) Program will be very useful for mapping and visualization of these reefs and coral assemblages. Such maps could then be the basis for allocation and stratification of the sampling effort because the assessment still requires SCUBA diving by trained personnel.

On the objectives and the sampling design

Before a national coral reef assessment program could be designed, basic decisions need to be made on the priority products [e.g., a scientific publication(s), a policy recommendation (s), draft legislation(s)], the target audience, and intended message (even the communications strategy) of the program. These basic decisions are made with the definition of the objectives, and consequently impact the decisions on the sampling units, the sampling design, and the critical and less critical metrics especially with regards to the scientific rigor required and the generality of the findings. The quantification of the impacts of marine protected areas, or the zoning of marine National Integrated Protected Areas System (NIPAS) sites are different from the objective of generating an assessment of the status of coral reefs in the country, and the corresponding sampling designs are necessarily different even if the methodologies involved are likely identical.

Effort for sampling the assessment units should be allocated in proportion to total reef area in the sampling strata defined by the objectives following a stratified random sampling design. Thus for example, if 20% of our reef assessment units in the country are in sampling stratum #1, then 20% of the reef assessment units sampled should come from randomly selected units in stratum #1. Potential national sampling strata are (1) biogeographic zones (North and South Pacific, West Philippine Sea, Sulu Sea, Visayas, and Celebes) and (2) clusters of locations (see, for example, Peñaflor et al. 2009). An example of more local (location level) sampling strata could be assessment units within and outside marine protected areas. The minimum number of units to be assessed per stratum will depend on the precision needed for the critical metrics, for example, a mean coral cover with a standard deviation of no more than 10%.

The objectives of the assessment program should be specified without being constrained by the amount of financial and human resources available for it. However, the decision on the sampling design is largely dependent on the objectives of the program and so the specification of additional strata will rapidly increase the sample size requirements and consequently the total cost of the assessment program. Hence, for example, a possible requirement to work outside municipal waters, to include the Kalayaan Islands and the deep offshore reefs of the Polillo Shelf and Reed Bank, or to evaluate the effectiveness of local marine protected areas within national strata, will likely increase the sample size requirements by at least two-fold and the costs by at least five-fold. Redefinition of the assessment units to include all areas with significant coral abundance (even if these are not in true coral reefs) will probably have the same impact on the sample size and costs. Note that many areas with coral communities around the large, high islands (e.g., in Luzon, Mindanao, Samar, and Leyte) are not on developed coral reef frameworks.

On the reef assessment

After the above steps are completed, actual assessment of the condition of these reefs and associated systems should then be conducted in as many reef sites as possible around the country. This will be a massive undertaking given the estimated 13,000-25,000 square kilometres of reefs in the Philippines. Perhaps the assessment program could initially be applied in pilot areas such as the West Philippine Sea, with its large reef area, local and international significance, and relatively developed capabilities of the academic institutions working in the area. Regardless, these assessments need to commence as soon as the procedures and methodologies, tasking, and institutional arrangements are worked out.

Processing and analyses of the data produced by the assessment should involve the classification of reefs into groups based on physical and ecological characteristics not subject to human perturbation (such as geomorphology, biogeographic zones). Once a typology of reef types based on these aforementioned characteristics is completed, "least-impaired" reference sites should be designated. These reference sites will then serve as the benchmark against which other reefs will be classified for purposes of defining allowable uses for each class. Reefs within typologies (e.g., northern Palawan fringing reefs) should then be classified (designated as Class A, Class B, Class C) relative to the reference sites for a given typology. For example, northern Palawan reefs with coral cover within 10% of the reference site designated for that typology area are classified as Class A, those with more than 10% but less than 20% cover from the reference

be classified as Class B, and so on. These classes should then have corresponding zoning guidelines recommended for implementation by the appropriate national government agencies and local governments (e.g., Class A reefs automatically get recommended as no-take protected areas, Class B reefs recommended as reserves where some fishing is allowed, and Class C reefs recommended for multiple uses). Relative positions and sizes of these zones should also be evaluated at the very least to meet best-use practices and standards to conserve biodiversity, sustain fisheries and ecotourism development, and minimize impact of natural disasters and climate change. Deployment of a high-resolution monitoring protocol and program should then follow soon.

Implementation phases for the ideal reef assessment program must also be defined since its design will be constrained by the costs involved. Ideally, a pilot area is selected to test the sampling design and the field and analytical methods involved, and serve as training ground for the personnel needed for the broader assessment. This pilot assessment can also be the opportunity for the target audience to examine the applicability and utility of the assessment products. A second phase could then be a nationwide assessment in all sampling strata by a single core team, albeit with a relatively small sample size. The latter could be increased in a third phase where subnational institutions will be undertaking the assessments in sites selected during the second phase. This however requires that a mapping of the locations, boundaries, and extent of all the assessment units be undertaken in the second phase along with their visualization. Thus all potential sampling units must be mapped and visualized even if no actual assessment (which requires SCUBA dives) is undertaken in these sampling units in the second or even third phases described above.

Ideally, the methodologies involved will produce permanent visual records (i.e., still and video images) to ensure consistency in the identification of taxa and categories and allow for more detailed post-processing in the future. Modified ARRAS/ CRAVAT technologies are ideal for the mapping and visualization phases since they can be used for synoptic assessments and not just for site selection. These technologies can be used to produce verifiable manta tow-type data for broad, mostly shallow areas. Coral Reef Targeted Research Common Sampling Program methods (see, van Woesik et al. 2009) can then be used for the assessment and monitoring since the sampling design, statistical power, and analytical methods have been worked out during the DOST-funded RESILIENT SEAS program. Sampling issues remain for the methodologies for studying reef fish and, to a lesser extent, seagrass and mangroves, and these urgently require deliberate, focused studies.

Going back to issues concerning the clarification of objectives and their impact on the sampling design, if the objective of the national assessment is simply to select areas for possible rehabilitation, all the steps described above will still be required up to the mapping and visualization, but not the actual diving assessment. However, if the impact of the reef rehabilitation at the national scale is to be evaluated, then the diving assessment and monitoring are important. The diving assessment is also necessary if the objective is to select priority conservation areas since the biodiversity metrics can only be evaluated with actual dives.

The nationwide reef assessment in relation to a national research and development program for Philippine coral reefs

As the above discussion suggests, a nationwide coral reef assessment is a necessary first step in a research and development program for coral reefs. If designed and implemented properly, the assessment program provides the basis for (1) an operational definition of coral reefs and associated habitats (=the assessment units), (2) a map of their distribution, extent, and condition, and (3) a typology of these reefs based on composition and diversity of component species and their relation to biogeography and climate. The first output is necessary given that most marine organisms are widespread but their environmental and economic significance varies considerably among our coastal areas. The definition thus allows us to initially focus on the coral reefs that are oldest and have the most significant aggregations of reef organisms. The second output serves as bases and/or baselines for many subsequent steps in the program. Examples include the location and measures of success and benefits of reef rehabilitation, the location and efficacy of conservation and protection measures for biodiversity, and the measurement and monitoring of the impact of human activities such as tourism and fisheries. The third output is more fundamental in that it serves as a guide which we can use to plan future research to better understand the processes behind the organization and maintenance of our important coastal ecosystems, and the necessary conservation steps that should follow.

But as the above discussion also tries to show, incorporating the objectives of these "downstream" efforts into the nationwide assessment requires a complex and expensive sampling design that will lead to compromises in the coverage and quality of the assessment.

In its present form, the proposed DOST-NACRE (National Assessment of Coral Reef Environments) Program already involves a number of compromises including the lack of a mapping and visualization project, the gaps in terms of the number of locations where the reef assessments will coincide with the reef fish assessments, assessments of associated habitats, and where hydrographic/ oceanographic parameters will be measured and modeled. The recently approved DOST-CRAVAT Program can potentially serve as the mapping and visualization component needed in NACRE but it is focused on improving the tools and methods and has only one demonstration site – the Verde Island Passage, which is made up of the coastal waters of five provinces. This is not a NACRE location but a DENR-CORVA (Coral Reef Visualization and Assessment) Program one.

Even the current design of CORVA does not complement

NACRE as well as most people perceive it to do. CORVA focuses only on 15 NIPAS (National Integrated Protected Area System) sites and these sites do not adequately represent the biogeographic zones and climate typologies that should stratify NACRE sampling. CORVA seeks to evaluate the impact of fish sanctuaries within the NIPAS sites and thus the basis for stratifying of sampling will be different from NACRE's. CORVA has the visualization and mapping component that NACRE lacks and this component is necessary for the CORVA objective of defining a zoning scheme within the NIPAS sites.

So how can NACRE, CORVA, and CRAVAT be harmonized in the interest of implementing a proper nationwide assessment of reefs? One step is for the three programs to agree on a common set of assessment metrics to focus on. Coral cover is a common metric among the three but this is not sufficient. Coral generic diversity and its concordance or non-concordance with reef fish diversity is another possible common metric if image-based methods are used in all three programs. Another step is to allow the three programs greater flexibility in the choice of sampling sites and stations. This means allowing NACRE to operate in NIPAS areas (e.g., the Verde Island Passage which is already a common area for CORVA and CRAVAT), and CORVA to operate in areas adjacent to their 15 NIPAS sites. A third step is the implementation of a multiple-tier scheme for sampling methodologies. This could entail the reef fish projects in CORVA and NACRE to revise their objectives and focus on detailed assessments of local impacts of fish sanctuaries and protected areas. The coral and associated habitat assessment projects in CORVA and NACRE could then align their sampling designs for the broader nationwide assessment goals. Hence the reef fish projects of the two programs should be more "CORVA-like" and the reef and associated habitat projects be more "NACRE-like". A visualization and mapping component must be added to NACRE, though, perhaps by initially adjusting the CRAVAT demonstration areas. The other projects of the three programs will also need to redefine their scope. To minimize the impacts on the budgets of CORVA and NACRE, the deployment of less-detailed methodologies involving less-specialized secondary teams (e.g., the application of revised Reef Check® methodologies for DENR, regional academic institutions, and local government staff) should be considered as complements. Reef Check methodologies allow for the assessment of human impacts on reef corals and other benthic invertebrates, and on reef fishes, by non-specialists who are supervised by scientists (see www.reefcheck.org). Both CORVA and NACRE also seek the establishment of monitoring sites but perhaps the scope and timetable for this could also be adjusted.

It seems most people concerned agree that a national assessment is needed soon. It appears though that the same individuals differ in what this national assessment should prioritize. We thus suggest that this document be used in structuring the discussion in the next coral reef "summit".

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CONFLICTS OF INTEREST

Both authors are involved in many of the past and proposed assessment projects mentioned in this manuscript.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Both authors contributed to the conceptualization and composition of this manuscript.

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