World Journal of Fish and Marine Sciences 7 (5): 352-361, 2015
ISSN 2078-4589

DOI: 10.5829/idosi.wjfms.2015.7.5.961

Coral Reef Monitoring and Conservation Plan: A Global Approach

[1-4]*Anisul Islam Mahmud*, [1-4]*Kassu Tesfaye Emiru*, [1-4]*Adrian Tot*, [1,4]*Roxane Beyns* and [1,4]*Ele´onore R.A. Viez*

[1]Department of Organism Biology, Université Libre de Bruxelles, Belgium
[2]Department of Biology, Vrije Universiteit Brussel, Belgium
[3]Department of Biology, Universitá Degli Studi Firenze, Italy
[4]INOS, Universiti Malaysia Terengganu

Abstract: The coral reef ecosystem is one of the most diverse on the planet. It is very important ecosystem for the overall functioning of the Earth. The services rendered to human, range from food provision to the recreational activity (tourism). But today we are facing the rapid loss of this ecosystem due to climate change and anthropogenic impacts. That's why many scientists are working on the conservation plan for monitoring the coral reefs. This review is initially a summary with some pros and cons of various coral reef monitoring methods practiced in different parts of the world. Indeed, it aims to provide a solid monitoring plan and conservation of coral reef islands.

Key words: Coral reefs · Tourism · Climate change · Anthropogenic impacts · Conservation

INTRODUCTION

The coral reef environments are complex and diverse marine ecosystems. They provide food and provide habitat for other species, they support the tourism industry, supplying sand beaches and act as natural barriers to coastal erosion by reducing wave energy. They are an appropriate and conducive environment for reproductive activities and colonization of the environment by fish, providing shelter and protection against predators. A complex reef structure and healthy reef helps to develop the quality of the ecosystem in question.

Coral reefs around the world are in decline [1, 2]. Over the past three decades, coral reefs worldwide have experienced major changes in structure and function due to both anthropogenic and natural impacts [3-6]. Virtually all of the most pervasive threats impacting coral reef ecosystems, including land-based and marine pollution, overfishing, global climate change and ocean acidification, have been suggested as synergists or facilitators of infectious disease. One phenomenon, which has recently gained the attention of coral reef scientists and managers, is diseases. Diseases affecting corals, particularly in the Caribbean, have increased in both frequency and severity within the last three decades and caused major community shifts on Caribbean reefs.

On smaller scales, overfishing [7,8], eutrophication [9-12] and direct physical disturbance [13] have also contributed to reef decline,while all of these stressors can potentially contribute to reef decline, synergistic effects among these stressor further exacerbate the situation [14,15].

Alleviation of these stressors requires management on appropriate scales with the potential to deal with overfishing, eutrophication and physical disturbance on a much smaller, local scale than thermal stress and hurricane impacts. Thus, an important area of study considers the relative contribution of local versus global scale stressors to the overall decline of coral reefs and if the alleviation of local stressors can potentially slow or reverse the current downward trajectory of reef systems [16].

In view of the above, the objectives of this study are to ensure sustainable development of the coral reef islands, propose a proper conservation and monitoring plan through studying literatures; that can be implemented by the local government authority and also

Corresponding Author: Anisul Islam Mahmud, Department of Organism Biology, Université Libre de Bruxelles, Belgium.

identify the gaps and short coming of the existing system. Indeed, this conservation and monitoring plan will take into account the presence of the endangered species including corals and sea turtle, aesthetic value as well as potential for sustainable tourism.

Coral Reef Monitoring Methods

Coral Health Index: The Coral Health Index (CHI) is composed of three metrics (benthos, fishes and microbes) to describe reef health that was proposed by Kaufman [17]. These are three different diagnostic parameters that work together to provide information about the health of a single coral reef ecosystem. That combination is important because even if one of the components (e.g. fishes) is low scoring, the overall score will be relatively high, indicating that the system can recover in the future.

In perfect synchrony and each metric can give information on the current state and future trends of a reef community. All three metrics are scaled to give a score from zero (degraded) to one (healthy) (Table 1). These scores are then equally weighted and averaged to give the final CHI score.

The methods for collecting data to calculate CHI are standard and reliable. Data are collected by scientifically trained people and can be performed quickly and consistently. There are many different ways to lay a transect or analyze photos and videos, but the methods chosen for CHI are based on being easy to perform and replicate. In order to compare the world's reefs, the methods must apply equally to the variety of reefs encountered.

Pros and Cons of CHI: This CHI method is simple, rapidly applicable in field and standard, whereas in a short time you can make many sampling with non-experts and its results comparable worldwide. The results are also easy to understand for a person not initiate the issue of coral reefs, therefore accessible to the general public. However even if the CHI has 3 components, these do not include criteria based on the physicochemical parameters of the environment, an important factor in the coral ecosystem and it doesn't consider the disease corals.

Coral Diseases: Raymundo *et al.* [18] described this method, where it mentioned that, there are two types of diseases observed in coral i.e. *infectious biotic diseases*; those that are caused by a microbial agent, such as a bacterium, fungus, virus, or protist, that can be spread between host organisms and negatively impact the host's health. Other forms of disease that considered as *abiotic diseases*; they do not involve a microbial agent but impair health, nonetheless. Examples may be those caused directly by environmental agents such as temperature stress, sedimentation, toxic chemicals, nutrient imbalance and UV radiation. For example, certain microbes secrete a toxin, which damages the host animal or plant. A good example of this is botulism; toxins released by the bacterium *Clostridium botulinum* cause a non-infectious but deleterious disease in organisms that consume it. Figures 1 and 2 represent diseases that observed during assessments done in Indo-Pacific, East African, West Atlantic and Red sea areas.

Table 1: CHI score of different types of coral reefs

Reef status	CHI score
Very healthy	0.80-1
Healthy	0.60-0.80
Fair	0.40-0.60
Degraded	0.20-0.40
Verydegraded	0-0.20

Hotspots for Coral Disease: The Caribbean has been referred to as a "hot spot" for disease; At least 82 percent of coral species in the Caribbean are host to at least one disease [19]. In the Pacific, the threat of coral diseases has been regarded as minor due to the large distances between reefs and island nations. Apparently, catchment areas of ocean are the main source of anthropogenic activities.

Pros and Cons of Coral Disease Assessment: Undoubtedly, coral disease assessment is one of good motoring method, where we can detect disease and plague in corals and anthropogenic influences. Although, it has some limitations i.e. have to measure water quality, need huge amount of fund to collect the sample, to analysis the sample, lots of man power needed and maintains general considerations i.e. permits, safety and sampling.

Coral Reef Ecosystem Assessment: This assessment method is proposed by Santavy *et al.* [20], where bio-criteria measure the relative condition of a given water resource based on the investigation of the health and diversity of its resident biota when compared, in part, to similar reference water bodies known to be unimpaired or minimally impaired by human activities. Impairment of the water body is judged by its departure from the bio-criteria.

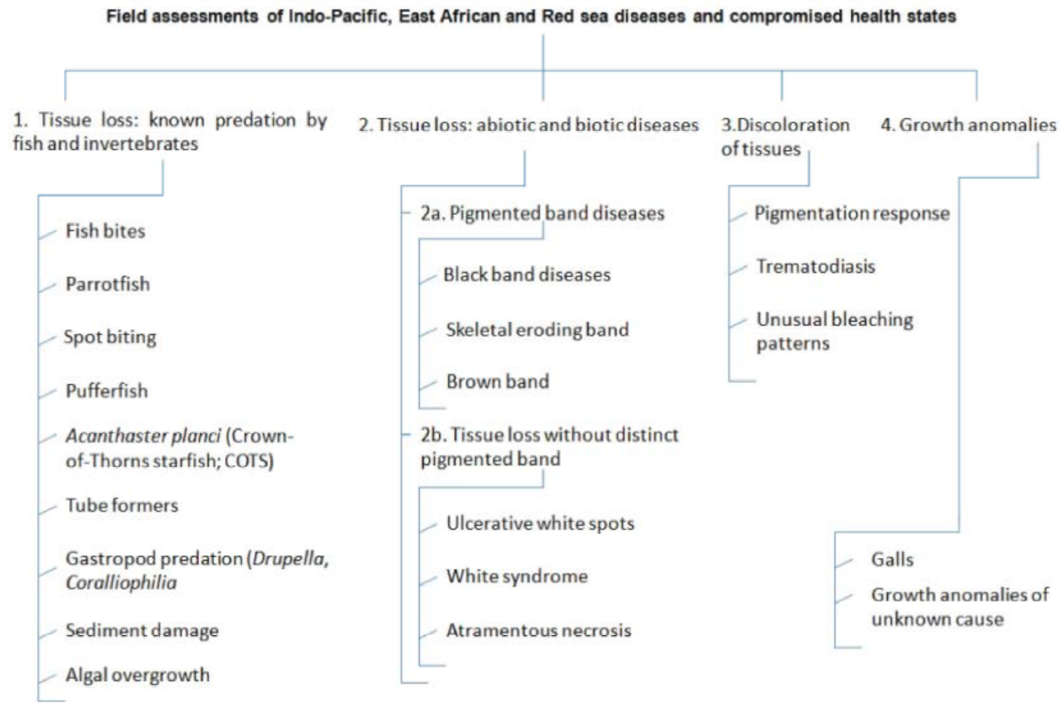

Fig. 1: Field assessments of Indo-Pacific, East African, Red sea diseases and compromised health states

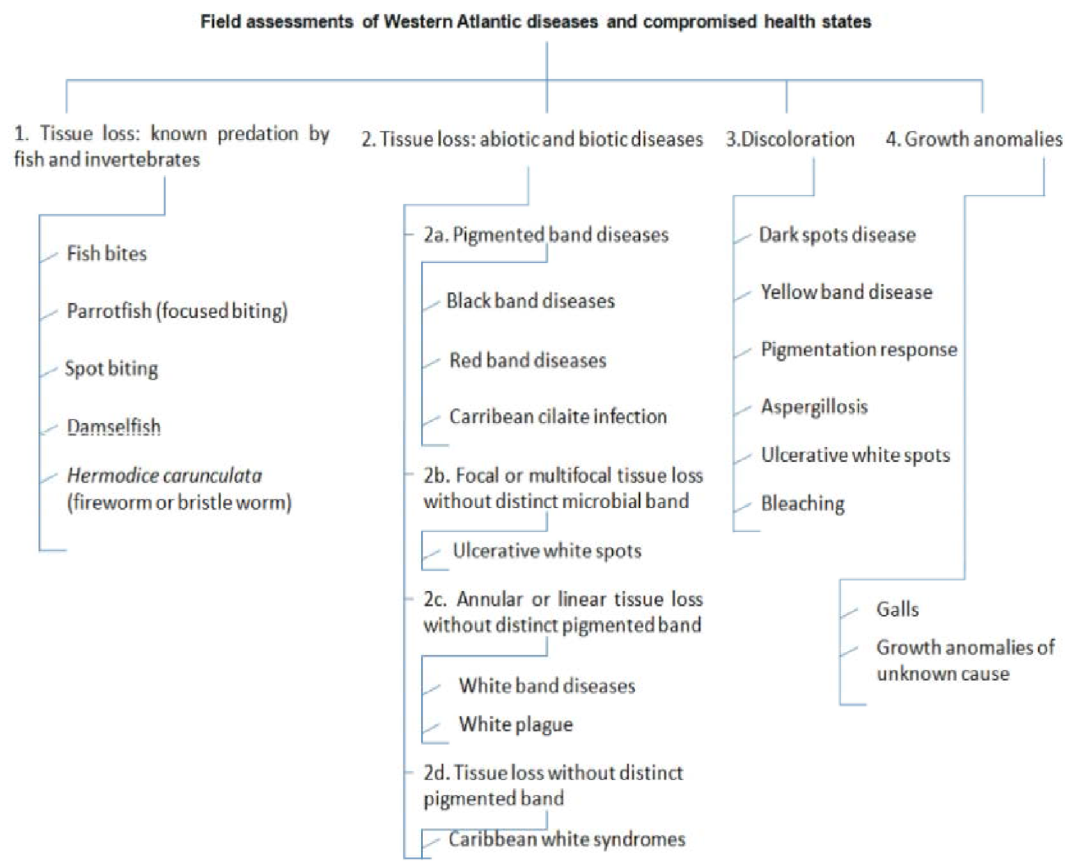

Fig. 2: Field assessments of Western Atlantic diseases and compromised health states

Table 2: Commonly used surveying techniques for coral reef monitoring

Survey	Description	Advantages	Disadvantages	Rank
Manta Tows	A diver/snorkeler is towed behind a small boat at a slow and constant speed for a fixed time interval.	Allows rapid coverage of large areas. Provides estimates of coral cover, dominant coral types, broad mortality estimates.	Detailed diagnostic or quantitative data not possible. Dependent on high water quality. May only be useful to estimate mortality cause if very visible (i.e. COTS, BBD).	1
Timed Swims	Diver swims for a fixed time in a straight line along a single depth gradient. All diseased corals in a 2m band noted: species, disease type, lesion number.	Provides semi- quantitative information on abundance of disease over large areas.	Not used for prevalence or incidence (no total colony count; survey area only estimated). Disease count categories used: rare (1-3 cases), moderate (4-12 cases), frequent (13-25 cases), abundant (26-50 cases), epidemic (51-100 cases), catastrophic (>100 cases)	2
Circular areas	Infected and healthy colonies of all species counted within a circular area (10m radius; 314 m^2). A stake pounded into substrate is used to define the pivotal center of the circle; a 10m transect tape is held by diver as she/he swims around the stake, keeping the tape taut.	Provides quantitative data on prevalence and incidence of diseases. If size measurements are included, population structure can be estimated. Best on flat reef substrates, in studies of single diseases (BBD, YBD).	Cannot be used on a reef slope because multiple zones may be included in a single sampling site. Does not provide information on coral cover unless combined with other measures. Impractical in areas with high cover and density.	2
Radial belt transect	Sampling circular areas in concentric belts (or arcs) around a pivot point. The area sampled is either a contiguous circle (radial sampling) or a series of rings (radial belt transect) around the pivot point.	Counts the total number of infected and healthy colonies of each species within the outer 8-10m of a circle (314m2 plot) and identifies all diseases.	Assessment of multiple permanent sites may be time consuming.	4
Belt transects	All corals within a predefined area (i.e.2x20m) are counted and disease presence recorded. 1m or 2m PVC stick is used to define a quadrat along a transect. May include more measurements such as colony size, coral cover and percent mortality	Can provide detailed data on prevalence based on a whole colony assessment, Population dynamics and health status. Long term monitoring of tagged colonies can provide data on colony fate (recovered/ dead/ stasis, etc.).	Requires multiple transects in each zone. With high diversity, high cover and abundant small corals, individual transects may require multiple dives to complete.	3
Line intercept transects	Can provide detailed data on prevalence based on a whole colony assessment, population dynamics and health status. Long term monitoring of tagged colonies can provide data on colony fate (recovered/dead/ stasis, etc.).	Allows rapid assessment of coral community structure, condition and prevalence of disease from a whole colony perspective. Provides information on size structure, colony density, coral cover.	Requires multiple transects throughout each zone to quantify prevalence. Does not provide a comparable assessment of area surveyed if corals vary in size between sites. Colony size based on actual measurements (or size classes) but percent colony mortality is estimated and may vary between observers.	4
Point intercept transects	Requires multiple transects in each zone. With high diversity, high cover and abundant small corals, individual transects may require multiple dives to complete.	Provides information on cover of various benthic organisms including coral as well as substrate types. Faster to use than Line intercept, if multiple survey sites are needed; allows rapid assessments.	Prevalence may be incorrectly assessed because relatively small overall area is examined along each transect. Does not provide detailed information on colony abundance (large colonies may be counted twice) or size structure.	4
Chain transects	Biotic and abiotic components identified directly under each link in chain. Rugosity estimated by determining ratio of the length of chain laid following bottom contours to the straight-line distance between start and end points of the transect.	Provides rapid information on reef rugosity, species diversity and cover.	Assesses a very narrow band of reef. Diseases and other factors may be missed unless the chain lands on the diseased portion of a colony.	2

Table 2: Continued

Quadrats	Quadrats of various sizes ($0.5m^2$, $1m^2$) are placed haphazardly, randomly, or at specific intervals along transects. Percent cover of all species and substrate types within quadrat area determined by counting number of quadrat subunits occupied by each category.	Provides quantitative information on cover of coral and other organisms With exception of large quadrats and substrates and qualitative data on types of disease present.	(i.e. 100x250m), poorly estimates disease prevalence, abundance, size or condition of corals; does not capture disease on the portion of a coral that falls outside the quadrat. Does not work well for large thicket-forming corals.	2
Photo quadrats	Quadrats of varying (<$1m^2$) are photographed using high resolution digital cameras and video.	Accurate assessment of cover and changes in cover (when using permanent quads). Less bottom time; data are analyzed in the lab, using image analysis software, such as NIH's free Image J software®.	Requires considerable lab work to analyze images. May fail to detect diseases and small colonies. Does not work well for large branching corals that form thickets. Resolution too low to identify many corals to species.	4

Descriptions taken from Bruckner [19], Edmunds [22], Porter and Meier [23], Antonius [24], Kuta and Richardson [25], English *et al.* [26], Bruckner and Bruckner [27], AGRRA [28], Jaap*et al.*[29], Santavy*et al.*[30], Weil *et al.*[31], Feingold [32]. For rankings: 5= Best and applicable, 4.5= Very good and applicable, 4= Good and applicable, 3= Good but not applicable, 2= Not good, 1= Poor methods

Biological criteria are, in effect, a practical approach to establishing management goals designed to protect or restore biological integrity [21]. Research is focused on developing methods and tools to support implementation of legally defensible biological standards for maintaining biological integrity, which is protected by the Clean Water Act (CWA). Under CWA authority and following national guidelines established by Environmental Protection Agency (EPA), States promulgate water quality standards to protect the physical, chemical and biological integrity of the nation's water bodies.

Pros and Cons of Coral Reef Ecosystem Assessment: This method is very thorough, precise and complete and allows a field study to cover the most important parameters representing the health of coral reefs. It also leaves the possibility for researchers to adapt the method depending on the question asked. This liberty allows for a very broad field of application ranging from simple ecological view, a large monitoring plan. However, this method is not really standardized (since adaptable) and not directly comparable with analytical points.

It has a serious field part, long and requiring the presence of many people (5 for 1 plot) and requires a very good knowledge of the fauna of coral reefs and only experts can realized that part. The calculations are also complex and require a lot of work interpretation and writing of large reports.

Survey Techniques for Reef Monitoring: There are almost 10 survey techniques (Table 2) mainly researchers and reef managers wanted to apply for reef monitoring e.g. manta tows, timed swimming, quadrats etc.

Data Management: In the 21st century scientific research is more data intensive and collaborative than in the past. It is important to study the data practices of researchers – data accessibility, reuse, discovery, preservation and, particularly, data sharing. Data sharing is a valuable part of the scientific method allowing for verification of results and extending research from prior results. A study of Piwowar *et al.* [33], looked at citation rates of researchers who shared over those who didn't and found sharing is associated with increased citation rate.

The hard work of so many researchers should not be wasted and left behind once the papers are published. We still have a way to go when it comes to standardization of data and well-curated databases for all different types data (physical data and computer data). These are not just the problems of the researcher, but of the Universities and research institutions, the journals and publishers, funding bodies and government institutions, which are already working to find ways of making sharing easier.

The Coral Reef Targeted Research and Capacity Building for Management (CRTR) Program is an international initiative designed to improve the knowledge base to help sustain the world's coral reefs for the future with a network of over 70 international scientists representing more than 50 institutions worldwide. The key task of the CRTR Program is to improve the integration of information across scientific experts, regions, time and space. One of the most practical ways to do so is to demonstrate where CRTR Working Groups can collect and share data to strengthen potential relationships across scales of investigation and to minimize the redundant and unnecessary collection of some data [34].

The amount of data the CRTR Program has collected and will continue to collect is immense. Successful completion of objectives and global comparisons relies on quality control and data management starting early and continuing throughout the Program. This will ensure that all regions are collecting data required for the targeted comparisons. Microsoft Access® has been used to create a relational database where data from all regions will be entered and kept at the Florida Institute of Technology as a central repository (however, database copies will reside with each CoE). Using the same database throughout all CoEs will provide a means of quality control to ensure all required data is collected and entered and will ease global comparisons without wasting time deciphering individual's Excel worksheets.

Conservation Plans for Coral Reef Islands: At the present time, the highest marine diversity is found among the coral reefs in a relatively small region of the tropical Indo-West Pacific Ocean (IWP). This region, called the East Indies Triangle extends from the northern Philippines to the Malay Peninsula and eastward to just beyond New Guinea [35].

More than 50% of all scleractinian species of Southeast Asia can be found in South China Sea. By the bye, it has been estimated that South China Sea is home to more than 3365 species of fishes and that a half of them are closely associated to coral reefs [36].

Much of Malaysia and the Philippines support dense human populations and all of their coral reefs have been degraded, many severely so. Without additional protection, the damaged reefs and overfished populations will not recover. The continuing degradation of coral reefs has become an agonizing reality to biologists, conservationists and to those of the general public who value them for their beauty and diversity of animal life.

Poorly managed tourism affects on reefs through anchor damage, garbage accumulation, diver damage and wastewater discharge from resort. Related problems include: the collection of shell and ornamental fish with the use of chemicals; dynamite fishing (although rarely observed, even in remote islands); sedimentation and wastewater pollution associated with rapid coastal development; jetty construction in several locations, which resulted in coral reef and sea grass degradation.

Since coral reef ecosystems supply a significant quantity of edible protein to island and coastal people, provide coastal protection through calcification and produce many non-food products, reef management on a sustainable yield basis is desirable for long-term use by people.

Made reef areas as marine reserve area, where it is being used as a way of maintaining the longevity of coral reefs themselves and the yields of fish and other resources from the reefs. A marine reserve constitutes a defined space to which some form of management and limited entry is applied, indeed there were common criteria used for selecting boundaries are resources, habitat, ecosystems, species and the space required for their interactions. Management may range from functional, where resource use occurs, to preservation, where entry is prohibited. Any coastal management project needs to consider linkages among all potential participants' fishermen communities, their leaders, local law enforcement officers, private business with local interests and provincial and national government organizations like resource management units or tourist authorities.

Combining local community participation, environmental education, economic incentives and legal mandates in a manner appropriate for a particular site together with long-term institutional support from government, non-government groups, academic or other institutions offers some possibility of success.

Regardless of reef quality and assuming no serious historical destruction, strong management can insure the opportunity for reef maintenance. Approaches that mobilize those people who use the resources daily are necessary to ensure wide participation and potentially long-lasting results.

Given the limited capacity and funding available for management in many countries, what is especially needed are simple tractable strategies that any manager could begin to adopt immediately to maximize long-term survival of the broadest range of coral communities and reef types. MPA managers should consider site-selection criteria that will allow coral communities that are reliably influenced by one or more protective environmental factors to be carefully monitored and adaptively managed. Managers should also manage sites down current of these areas to enhance conditions for larval settlement and recovery of these dependent areas.

For communities to trust and support governmental programs it is recommended that:

- The law is modified in order to give more importance to the role communities play in the management of natural resources;
- Secure and clear mechanisms for the administration of financial resources exist;
- Compromises are clearly defined and accepted by all stakeholders;

Table 3a: Tourist activities with direct impacts and actual and/or potential impacts in coral reefs

Activities with direct impacts	Actual and/or potential impacts on corals
Snorkeling	Physical damage (breakage, lesions)
	Kicking on the corals
SCUBA diving	Physical damage (breakage, lesions)
Motor boating and yachting	Physical damage from anchoring
	Physical damage from boat groundings
Fishing	Contribute to over-exploitation of reef fish stocks
	Compete with local fishermen
Collecting (shells, lobsters, conch, coral)	Threatening local survival of rare species,
	Contributing to over-exploitation and
	Competing with local fishermen

Table 3b: Tourist activities with indirect impacts and actual and/or potential impacts in coral reefs

Activities with indirect impacts	Actual and/or potential impacts on corals
Resort development and construction	Increased sedimentation, Nutrient enrichment
Resort operation	Leaching of toxic substances from inappropriate waste disposal Litter (especially plastics)
Sea food consumption	Over-exploitation of high-priced resource species (snapper, grouper, spiny lobster, conch)
Demand for marine curiosities	Exploitation of rare/ endangered/ vulnerable species such as shells, black coral, turtles
Construction of artificial beaches and beach replenishment	Increased sedimentation (from sand removal or from beach instability)
Airport construction or extension	Increased sedimentation from dredging and in filling
Marine construction	Increased sedimentation from dredging
Marine operation	Pollution from inappropriate disposal of oils and paint residues
Pollution from fueling Motor boating and yachting	Nutrient enrichment from sewage disposal
Pollution from fueling Cruise ships	Nutrient enrichment from illegal sewage disposal

- Agreements made between the community and the authorities are legalized, respected and fulfilled;
- Surveillance and endorsement is efficient and continuous;
- Management effectiveness is evaluated and improved; and
- Communities obtain positive conservation and financial benefits as a result of their involvement in management within a short time frame.

Prevention measures and the mitigation of coral reef damage, through coral reef zoning and temporary closure of degraded coral reefs, are important interventions under the integrated coastal zone management (ICZM) approach. But, conservation organizations and governments must be persuaded that the present diversity in reef areas and evolutionary future of the marine world is at stake.

Sustainable Touristic Plan for Reef Islands: Coral reefs are under threat, declining and degrading due to a combination of natural and anthropogenic factors. Fifty-eight percent of the world's reefs are potentially threatened by human activity. Over exploitation and coastal development pose the greatest potential threat [37]. At the same time we know that tourism can be considered one of the most remarkable socio-economic phenomena for this century [38]. Because of their incredible diversity and beauty-recognized worldwide, the coral reef is one of the major attractive places for touristic purpose. However, tourist recreations have deleterious effect on the health of coral reef (Tables3a & 3b).

How to Combine Tourism and Conservation Program for Coral Reef?: The solution is to propose and develop sustainable tourism activities. According to Butler [39], tourism which is developed and maintained in an area in such a manner and scale, that it remains viable over an indefinite period and does not degrade or alter the environment in which it exists to such a degree that it prohibits successful development and well being of other activities and programs. All tourism activities of whatever motivation –holidays, business travel, conferences, adventure travel and ecotourism – need to be sustainable. These are the reasons of tourist impact on reefs (Table 3a & 3b), we would like to propose the development of sustainable tourism in reef islands. This plan need to consider the damage causes directly through tourist e.g. snorkeling and diving in limiting the open area for this activity and ensure a code of good practices. Forbidden fishing and collecting shell and corals in the island area. And for indirect impact, should try to minimize it. Apparently, the important part is to create awareness on the importance of coral reefs among the local people and tourists.

Proposed Reef Monitoring Method: Remote sensing has been widely used in more than four decades. The primary role of remote sensing has been to map coastal recourses as part of a marine spatial planning activity. With the emergence of new, improved sources of data, the maps became more detailed and accurate than before. Management is enhanced with better maps and a wide range of useful tools. Some of the examples include, mapping the potential response of coral reefs to thermal stress, mapping of hotspots of marine diversity and mapping the locations of critical nursery habitats.

The method would like to propose that, to monitor reef area using the remote sensing mapping, where the image can be classified into 5 classes: bleaching corals, turf algae, macro algae, sand, coralline algae and other (non classified) [40, 41]. Mahmud *et al.* [42] also classified (maximum likelihood) using normal distance i.e. sand, shallow water, shallow corals, deep corals and deep water through marine park mapping using Worldview-2 high resolution satellite imagery.

The effectiveness of a survey apply remote sensing is influenced by a number of factors, i.e. water visibility, water depth, currents, tide patterns and so on.

Marine protected areas (MPA) can be easily accessible for authorized person i.e. scientists, researchers, managers etc., but a careful planning is needed for other peoples.

Airborne and satellite remote sensing technologies are increasingly being used for monitoring coral reef habitats. To create accurate and reliable maps, calibration of mapping algorithms and validation of output maps is necessary [43]. A common limitation of most image based mapping of coral reefs, which may be responsible for its limited uptake by managers, is an inadequate or absent validation program [43-45]. A variety of benthic survey methods have been used for validation, such as visual checks [46], line intercept [47], video [48] and digital still surveys [40]. But according to Roelfsema *et al.* [49], the best method of survey using remote sensing is an analysis of high resolution and a validation (calibration) method of photographic transect field method with 1024 photos. However, using a 12-point photo analysis but this result in less detailed analysis of photos can reduce the processing time. In association with the CHI method survey, we judge to apply the method of using 12 points photo analysis.

CONCLUSION

We often tend to talk about the action of human on the environment as something always negative; as the destruction, over-exploitation of resources. The effort of conservation and management of coral reefs by researchers show us, how the human conscious of its impact and try to minimize it. The problem of the disappearance of coral reefs is a global problem and requires intervention and international concerns. In the case of our study underscores that need to find a method, which can be applicable for all authorities, where they can apply this in convenient location with a synthetic, fast and inexpensive way. The results of this method should be understandable for the general people. Tourism is seen as a mark of globalization and consumerism. In the last decade awareness about sustainable tourism has increased, thus raising awareness among the tourists for a more environmental friendly management.

REFERENCES

1. Bruno, J.F., E.R. Selig, K.S. Casey, C.A. Page, B.L. Willis, C.D. Harvell, H. Sweatman and A.M. Melendy, 2007. Thermal stress and coral cover as drivers of coral disease outbreaks. PLoS Biology, 5: 1220-1227.
2. Gardner, T.A., I.M. Cote´, J.A. Gill, A. Grant and A.R. Watkinson, 2003. Long-term region-wide declines in Caribbean corals. Science, 301: 958-960.
3. Bellwood, D.R., T.P. Hughes, C.Folke and M. Nystrom, 2004. Confronting the coral reef crisis. Nature, 429: 827-833.
4. Harvell, C.D., R. Aronson, N. Baron, J. Connell, A. Dobson, S. Ellner, L. Gerber, K. Kim, A. Kuris, H. McCallum, K. Lafferty, B. McKay, J. Porter, M. Pascual, G. Smith, K. Sutherland and J. Ward, 2004. The rising tide of ocean diseases: unsolved problems and research priorities. Frontiers in Ecology and the Environment, 2: 375-382.
5. Hoegh-Guldberg, O., P.J. Mumby, A.J. Hooten, R.S. Steneck, P. Greenfield, E. Gomez, C.D. Harvell, P.F. Sale, A.J. Edwards, K. Caldeira, N. Knowlton, C.M. Eakin, R. Iglesias-Prieto, N. Muthiga, R.H. Bradbury, A. Dubi and M.E. Hatziolos, 2007. Coral reefs under rapid climate change and ocean acidification. Science, 318: 1737-1742.
6. Hughes, T.P., A.H. Baird, D.R. Bellwood, M. Card, S.R. Connolly, C.Folke, R.K. Grosberg, O. Hoegh-Guldberg, J.B.C. Jackson, J.A. Kleypas, J. Lough, P. Marshall, M. Nystrom, S.R. Palumbi, J.M. Pandolfi, B. Rosen and J. Roughgarden, 2003. Climate change, human impacts and the resilience of coral reefs. Science, 301: 929-933.

7. Jackson, J.B.C., 1997. Reefs since Columbus. Coral Reefs, 16: 23-32.
8. Hughes, T.P., D.R. Bellwood, C.S. Folke, L.J. McCook and J.M. Pandolfi, 2006. No-take areas, herbivory and coral reef resilience. Trends in Ecology and Evolution, 22: 1-3.
9. Grigg, R.W., 1994. Effects of sewage discharge, fishing pressure and habitat complexity on coral ecosystems and reef fishes in Hawaii. Marine Ecology Progress Series, 103: 25-34.
10. McClanahan, T.R., E. Sala, P.A. Stickels, B.A. Cokos, A.C. Baker, C.J. Starger and S.H.I.V. Jones, 2003. Interaction between nutrients and herbivory in controlling algal communities and coral condition on Glover's Reef, Belize. Marine Ecology Progress Series, 261: 135-147.
11. Fabricius, K.E., 2005. Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. Marine Pollution Bulletin, 50: 125-146.
12. Gruner, D.S., J.E. Smith, E.W. Seabloom, S.A. Sandin, J.T. Ngai, H. Hillebrand, W.S. Harpole, J.J. Elser, E.E. Cleland, M.E.S. Bracken, E.T. Borrer and B.M. Bolker, 2008. A cross- system synthesis of consumer and nutrient resource control on producer biomass. Ecology Letters, 11: 740-755.
13. McClanahan, T.R., E. Verheij and J. Maina, 2006. Comparing the management effectiveness of a marine park and a multiple-use collaborative fisheries management area in East Africa. Aquatic Conservation of Marine and Freshwater Science, 16: 147-165.
14. Hughes, T.P. and J.H. Connell, 1999. Multiple stressors on coral reefs: a long-term perspective. Limnology and Oceanography, 44: 932-940.
15. Porter, J.W., S.K. Lewis and K.G. Porter, 1999. The effect of multiple stressors on the Florida Keys coral reef ecosystem: A landscape hypothesis and a physiological test. Limnology and Oceanography, 44: 941-949.
16. Kaufman, L. and J. Tschirky, 2010. Living with the sea. Science and Knowledge Division, Conservation International, Arlington, VA, USA.
17. Kaufman, L., S. Sandin, E. Sala, D. Obura, F. Rohwer and T. Tschirky, 2011. Coral Health Index (CHI): measuring coral community health. Science and Knowledge Division, Conservation International, Arlington, VA, USA.
18. Raymundo, L.J., C.S. Couch, C.D. Harvell, J. Raymundo, A.W. Bruckner, T.M. Work and G.S. Aeby, 2008. Coral Disease Handbook Guidelines for Assessment, Monitoring & Management.
19. Bruckner, A.W., 2002. Priorities for effective management of coral diseases. NOAA Technical Memorandum NMFS-OPR-22, pp: 54.
20. Santavy, D.L., W.S. Fisher, J.G. Campbell and R.L. Quarles, 2012. Field Manual for Coral Reef Assessments. U.S. Environmental Protection Agency, Office of Research and Development, Gulf Ecology Division, Gulf Breeze, FL. EPA/600/R-12/029.
21. Jameson, S.C., M.V. Erdmann, G.R. Gibson and K.W. Jr. Potts, 1998. Development of biological criteria for coral reef ecosystem assessment. USEPA, Office of Science and Technology, Health and Ecological Criteria Division, Washington, DC.
22. Edmunds, P.J., 1991. Extent and effect of black band disease on a Caribbean reef. Coral Reefs, 10: 161-165.
23. Porter, J.W. and O.W. Meier, 1992. Quantification of loss and change in Floridian reef coral populations. American Zoologist, 23: 625-640.
24. Antonius, A., 1995. Coral diseases as indicators of reef health: Field methods. Proceedings of the Second European Meeting of International Society of Reef Studies, Publications du Service Geologique du Luxembourg, 29: 231-235.
25. Kuta, K.G. and L.L. Richardson, 1996. Abundance and distribution of black band disease on coral reefs in the northern Florida Keys. Coral Reefs, 15: 219-223.
26. English, S., C. Wilkinson and V. Baker, 1997. Survey Manual for Tropical Marine Resources, 2nd Ed., Australian Institute of Marine Science, Townsville, pp: 390.
27. Bruckner, A.W. and R.J. Bruckner, 1997. The persistence of black-band disease in Jamaica: impact on community structure. Proceedings of the Eighth International Coral Reef Symposium, Panama, 1: 601-606.
28. AGRRA, 1998. Atlantic and Gulf Rapid Reef Assessment Protocol. http://coral.aoml.noaa.gov/agra/method.htm.
29. Jaap, W.C., J.W. Porter, J. Wheaton, K. Hackett, M. Lybolt, M. Callahan, C. Tskos, G. Yeanev and P. Dustan, 2000. Coral reef monitoring project executive summary.EPA Science Advisory Panel Key Colony Beach.
30. Santavy, D.L.E., E. Mueller, E.C. Peters, L. MacLaughlin, J.W. Porter, K.L. Patterson and J. Campbell, 2001. Quantitative assessment of coral diseases in the Florida Keys: Strategy and methodology. Hydrobiologia, 460: 39-52.

31. Weil, E., I. Urreiztieta and J. Garzón-Ferreira, 2002. Geographic variability in the incidence of coral and octocoral diseases in the wider Caribbean. Proceedings of the Ninth Coral Reef Symposium, Bali, 2: 1231-1237.
32. Feingold, J.S., 1988. Ecological studies of a cyanobacterial infection on the Caribbean sea plume *Pseudopterogorgiaacerosa* (Coelenterata: Octocorallia). Proceedings of the Sixth International Coral Reef Symposium, Townville, pp: 57-162.
33. Piwowar, H.A., R.S. Day and D.B. Fridsma, 2007. Sharing Detailed Research Data Is Associated with Increased Citation Rate. PLoS ONE, 2: e308.
34. Van Woesik, R., J. Gilner and A. Hooten, 2009. Standard Operating Procedures for Repeated Measures of Process and State Variables of Coral Reef Environments.Coral Reef Targeted Research and Capacity Building for Management Program, Centre for Marine Studies, Gerhmann Building, The University of Queensland, St Lucia, Qld 4072.
35. Briggs, J.C., 1995. Global Biogeography. Elsevier. Amsterdam, Netherlands.
36. Arai, T., 2014. Diversity and conservation of coral reef fishes in the Malaysian South China Sea. Reviews in Fish Biology and Fisheries, pp: 1-17.
37. Bryant, D., L. Burke, J. McManus and M. Spalding, 1998. Reefs at risk: a map-based indicator of threats to the world's coral reefs.
38. Neto, F., 2003. A new approach to sustainable tourism development: Moving beyond environmental protection. In Natural Resources Forum. Blackwell Publishing Ltd., 27: 212-222.
39. Butler, R.W., 1993. Tourism–an evolutionary perspective. Tourism and Sustainable Development: Piloting, Planning, Managing, Department of Geography Publications Series, 37: 27-43.
40. Joyce, K., S. Phinn, C. Roelfsema and D. Neil, 2004. Combining Landsat ETM and Reef Check for mapping coral reefs: An example from the southern Great Barrier Reef, Australia. Coral Reefs, 23: 21-25.
41. Hodgson, G., W. Kiene, J. Mihaly, J. Liebeler, C. Shuman and L. Maun, 2004. Reef Check Instruction Manual: A Guide to Reef Check Coral Reef Monitoring. Reef Check, Institute of the Environment, University of Californiaat Los Angeles, Los Angeles, pp: 92.
42. Mahmud, A.I., C. Gaboriaud, K.T. Emiru and E.R.A. Viez, 2015. Pinang Island: Marine park mapping using Worldview-2 high-resolution satellite imagery. World Applied Sciences Journal, 33: 797-801.
43. Green, E. and A.W. Bruckner, 2000. The significance of coral disease epizootiology for coral reef conservation. Biological Conservation, 96: 347-361.
44. Ahmad, W. and D.T. Neil, 1994. An evaluation of Landsat Thematic Mapper (TM) digital data for discriminating coral reef zonation: Heron Reef (GBR). International Journal of Remote Sensing, 15: 2583-2597.
45. Holden, H. and E. LeDrew, 1998. The scientific issues surrounding remote detection of submerged coral ecosystems. Progress in Physical Geography, 22: 190-221.
46. Mazel, C.H., M.P. Strand, M.P. Lesser, M.P. Crosby, B. Coles and A.J. Nevis, 2003. High-resolution determination of coral reef bottom cover from multispectral fluorescence laser line scan imagery. Limnology and Oceanography, 48: 522-534.
47. Andrefouet, S., M. Zubia and C. Payri, 2004. Mapping and biomass estimation of the invasive brown algae *Turbinariaornata* (Turner) *J. Agardh* and *Sargassummangarevense* (Grunow) Setchell on heterogeneous Tahitian coral reefs using 4-meter resolution IKONOS satellite data. Coral Reefs, 23: 26-38.
48. Louchard, E.M., R.P. Reid, F.C. Stephens, C.O. Davis, R.A. Leathers and D.T. Valerie, 2003. Optical remote sensing of benthic habitats and bathymetry in coastal environments at Lee Stocking Island, Bahamas: A comparative spectral classification approach. Limnology and Oceanography, 48: 511-521.
49. Roelfsema, C.M., S.R. Phinn and K.E. Joyce, 2006. Evaluating benthic survey techniques for validating maps of coral reefs derived from remotely sensed images. In Proc 10th Int. Coral Reef Symp., 1: 1771-1780.