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Performance of Coral Reef Management within Marine Protected Areas: Integrating Ecological, Socioeconomic, Technological, and Institutional Dimensions

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Abstract

This research studied the characteristics and approaches that contributed to the successful of coral reef management (CRM) efforts. One such characteristic occurred in most case studies was the importance of integrating ecological, socio-economic, technological use, and institutional dimensions during all processes. Based on a multi-dimensional analysis, the sustainability of CRM was 56.34% cumulatively, indicating a moderate level of management. This study further suggested the importance to improve technology and institution to achieve an effective CRM since both dimensions have contributed only 38.80% and 49.26% respectively. Stakeholder involvement was also central to the success of networking development within the management of Cenderawasih Bay National Park, specifically in facilitating the integration of ecological, socioeconomic, political will, and local cultural objectives in achieving an optimum planning objectives. Compilations of baseline information (both scientific and local knowledge) were important to evaluate the effectiveness of all processes and for adaptive management to increase its potential in the management strategies. Balancing the integration of all management dimensions (ecology, socio-economic, technology, and institution) in the whole processes with specific attributes in each case, would lead to an adaptive management for the implementation of conservation and management process.

Keywords: coral reef, management performance, integrated dimensions, marine protected areas.

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Introduction

Coral reef ecosystem is essential for human survival since such ecosystem provides food sources for substantial human needs and coastal protection structures for most tropical islands, as well as the main contributor for foreign exchange earnings (Salm *et al*. 2000). Developments in recent decades suggest that coral reefs are the most endangered ecosystems in the global tropics (Reaser *et al*. 2000; Wilkinson 2000; Pandolfi *et al*. 2003). Examples of increased pressures on coral reefs that have caused great losses to the existence of coral have been reported from various regions, such as in the Caribbean (Gardner *et al*. 2003), U.S. Virginia Island (Watlington 2006), Africa (Garrison *et al*. 2003), Tropical Western Atlantic (Levitus *et al*. 2000) and Indonesia (Nontji 2008). Evidences suggest that the simultaneous pressure from various sources is the deadly cause of reef degradation. Such include the coral bleaching in Eastern Caribbean due to temperature rise associated with anthropogenic activities (Donner *et al*. 2007); as well as evidence of coral bleaching, coral disease and mortality in the US Virgin Islands (Manzello *et al*. 2007).

Increased pressures on coral reef ecosystems globally and regionally, occur as a result of loSacal population growth and development. Rapid development is exponentially responsible for the increase rate of sedimentation due to land sediments run-offs into the ocean (Brooks *et al*. 2007), increasing the sediment deposits on the reefs (Nemeth & Nolish 2001). Industrial activities such as transportation equipments maintenance, oil and pollution, have all contributed to the increased inputs of toxic chemicals into the coastal environment which reduce photosynthesis rate (Owen *et al*. 2002). In addition, fishing activities have also increased along with fishing gear development, which significantly have lowered the biomass of the economically important reef fishes (Rogers & Beets 2001). The high dependence of coastal communities on reef fisheries, have resulted in a less efficient utilization through the use of destructive fishing methods that leads to overfishing (Wiadnya *et al*. 2005).

This above argument emphasizes the importance of incorporating multi-dimensional aspects (ecological, socio-economic, technological, and institutional) in the management of coral reef ecosystem. An integrated approach is believed to be able to create and strengthen CRM, which stresses conservation and protection while enhancing public welfare. On the other hand, study of marine protected areas (MPA) management, is currently lacking integration among various aspects and dimensions

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as shown by various studies such as economic and social implications (Sanchirico *et al* 2002); biologically successful but socially fail (Christie 2004); social dimension and policy implications (Mascia 2003); cultural and socio-economic impacts (Badalamenti *et al*. 2000; West *et al* 2006), as well as science and management (Mumby & Steneck 2008). Furthermore, the success of MPA management through the integration of various aspects have been reported; socio-economic, political and science (Lundquist & Granek 2005); and economic, biological resources and community involvement (Pollnac *et al*. 2001). This suggests that an analysis of just 1 or 2 aspects (dimensions) in CRM performance is insufficient, given that resource management process engages many dimensions. The conditions of each interconnected dimension related to CRM processes need to be assessed to produce an integrated CRM. This research delves at the characteristics and approaches that contribute to the success of CRM. Successful characteristic emphasizes the integration of various management dimensions (ecological, socio-economic, institutional, and technological use) at all processes in achieving an effective management strategy.

Methods

Research site The study began in October 2010 as a preliminary study to attain an overview of the study area. The study was further conducted in March–June 2011 to get a comprehensive picture of the ecological, socio-economical, and institutional dimensions of Cenderawasih Bay National Park (CBNP) within the Regency of Wondama Bay. The study was continued in May and again in June 2012 in the area of CBNP that were located in the Regency of Nabire of Papua Province and Wondama Bay of West Papua Province (Figure 1).

Type, sources of data and approaches The study began by establishing a research framework of the assessment of perspectives and issues relevant to the management of coral reef ecosystems in the CBNP. The objective of the framework was to get an insight into the effects of management activities and to conduct studies on the management activities over the years. The next step was to present a framework analysis of various management dimensions (ecological, socio-economic, technology and institution) in the form of a matrix to be assessed from the perspective of CRM.

The study was conducted at several coral reef research stations that were previously used by CBNP in collaboration with CI (Conservation International), TNC (The Nature Conservation), WWF (World Wildlife Foundation), UNIPA (The State University of Papua) (Lazuardi 2006). Measurement of oceanographic data followed the station's points of observation and locations that were significantly affected by the mainland activities.

Socio-economic data retrieval was determined through purposive sampling (Cochran 1977), taking into account locations of the island and the mainland, public access to coastal resources and affordability of marketing. Information was gathered from as many as 343 household respondents including fishermen. Stakeholder analysis involved a total of 33 people representing individuals and institutions, who were drawn hierarchically (village, district, regency, provincial and national levels) representing all interests affecting the Traditional Utilization Zone (ZPT-MPA).

Data analysis Data was processed and analyzed using Multi Dimensional Scaling (MDS) (Kavanagh & Pitcher 2004). Each attribute of every dimension was given a rank that reflected the condition of CRM from the perspectives of

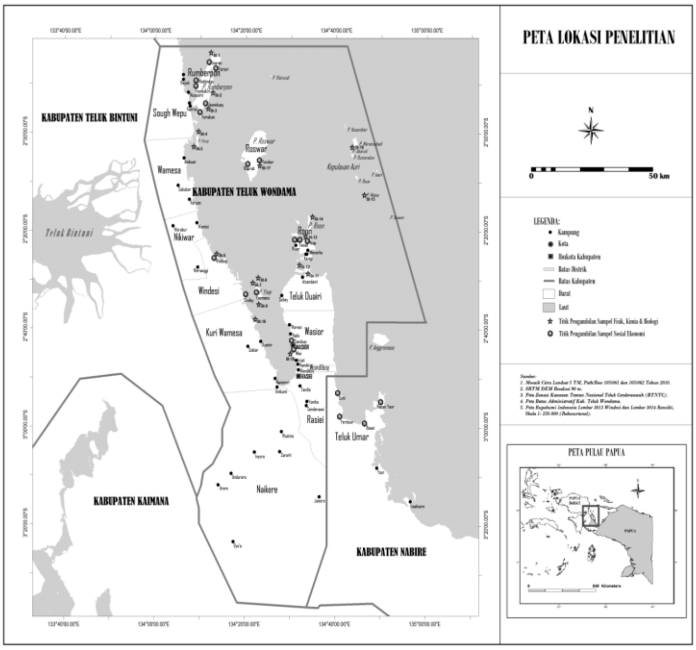

Figure 1 Map of study site, reef observation sites, water quality, and socio-economic data collection sites.

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various dimensions (ecological, socio-economic, technological, and institutional). The rank of each attribute was analyzed to determine the status of the assessed management relative to the 2 main reference points, the "good" point and "poor" point. Each category of various management dimensions consisted of several attributes that were ranked and sorted in values (Table 1).

The produced matrix was an interval data that demonstrated the value of good and poor ratings. The ratings were then normalized to minimize stress. SPSS software was used in the development of MDS to determine the position of CRM which was visualized in 2 dimensions (horizontal and vertical axis). The projection of the points on the horizontal line were done through rotation process,

Table 1 Dimension and attributes of Coral reef management performance assessment

Ecological dimension	Operational definition
Coral coverage	Level of coral coverage (%)
Reef fish diversity	Reef fish diversity based on number of species
Flow of current	Flow of current (m/sec)
Temperature	Level of temperature (˚C)
Salinity	Level of salinity (o/oo)
Clarity	Level of water clarity (m)
Depth	Level of water depth (m)
Endemic species	Presence of endemic species
Sedimentation	Sediment loads (mg ℓ^{-1})
Water quality	Water standard based on Ministry of Environment KLH 51/2004.
Level of fish exploitation	Level of exploitation of reef fishery utilization
Technological dimension	
Type of fishing gear	Number of still and move equipments
Selectivity of fishing gears	Level of selectivity of fishing gears
Line transportation	Availability of line transportation
Type of boat/ship	Type of boat used, such as motorized and non motorized boats, ship
Harvest handling	Handling of harvest (processing and preservation)
Socio-economic dimension	
Potential conflict	Potential conflict in resource utilization
Education level	Level of education of respondents
Environmental knowledge	Level of community understanding on environment and protected areas
Value of coastal area ownership	Level of coastal area ownership
Dependence on reef fishery	Composition of yields
Allocation of utilization period	Time allocation for reef fishery utilization
Education & research	Availability of environmental education and research
Tourist guides	Availability of tourist guides
Scuba equipments rental	Availability of diving equipments
Domestic tourists	Number of domestic tourists
International tourists	Number of international tourists
Tourist objects	Availability of tourism objects such as for diving and snorkelling
Utilization zone	Allocation of utilization zone, include none; available but violated, available, available and obeyed.
Income	Average household income to the minimum wage of West Papua
Institutional dimension	
Formal regulation	Availability of formal regulations
Stakeholders	Participation of stakeholder in management
Compliance to the law	Level of compliance
Monitoring & evaluation	Availability of monitoring tools and resource evaluation
Village figure	Presence of community figures
Extension	Information delivery related to institutional strengthening
Local traders	Presence of traders in fishery products marketing
Tradition/culture	Current local wisdoms in resources utilization
Conservation cadre	Present of conservation forum at local level

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with an extreme "poor" valued at 0% and the extreme "good" valued at 100%. Positions of the assessed management status were between the 2 extremes. In this study, 4 categories of CRM status were used based on a scale of 0–100% (Table 2). Comparative analysis of the management status among dimensions was visualized in the form of a kite diagram, which illustrated the shape of inter-dimensional integration.

Leverage analysis was done to select the most sensitive attributes contributed to CRM activities. Effect on each of the attributes was observed in the form of changes in root mean square (RMS) ordination, particularly on the x-axis or the scale of management. The larger the RMS value changes due to the loss of a particular attribute, the greater the role of these attributes in the formation of scale value management, or the sensitive attributes in CRM. Evaluation of the influence of randomized errors on the process to estimate CRM value ordination is assessed using Monte Carlo analysis.

Results and Discussion

Performance of CRM The stress value obtained from MDS analysis, both the combination of all dimensions and analysis on each dimension showed a value of < 25% (Table 3). Stress value of less than 0.25 and R2 approaching 1.00 indicated a strong analytical result to be used and applied in determining the status CRM. These results are supported by Kavanagh and Pitcher (2004) who state the criteria stress $\leq$ 25% is acceptable for MDS results. Technological and institutional dimension caution is warranted given the highest statistical value (stress and iteration).

Monte Carlo analysis resulted in an insignificant difference between the MDS value and Monte Carlo analysis ordination at 95% confidence level with relatively very small difference for each dimension (Table 4). The value difference in the dimensions of CRM indicated that:

1 an error in developing attribute score was relatively small,
2 variations in scoring as a result of difference opinion or interpretation was relatively small,
3 the repeated iteration process was relatively stable, and,
4 errors in data entry or data loss could be avoided.

Therefore, the analysis indicated that MDS analysis had a high degree of confidence, and can be concluded that the results of this study could be applied and could be used as an instrument for evaluating CRM.

CRM Inter-dimensional integration MDS analysis of the 41 CRM attributes of the 4 management dimensions (ecology, socio-economic, technology, and institution) gave a figure of 56.34% in the scale of 0–100 (Figure 2). Such value showed that CBNP activities were still in fairly sustained condition based on the category criteria on Table 2. Nevertheless, such condition could be enhanced by improving the various management dimensions. MDS analysis showed CRM status from the perspective of various management dimensions (Figure 3). Utilization of technology and institutional dimensions comprised of 38.80% and 49.26% respectively, indicating an insufficient CRM. Thus improvement efforts were necessary to achieve good and effective status. On the contrary, the ecological (71.47%) and socio-economic (63.22%) dimensions were both indicating CRM at adequate level.

In the concept of CRM sustainability, each dimension did not necessarily must show the same amount of contributions (Figure 3), but in many cases the most important thing was how to synergize the attributes of each dimension in the form of management activities. Although no dimensions were in conditions of poor management, but serious attention to maximize CRM function of technological and institutional dimensions remain sought. Priority should be made toward the improvement of attributes to increase the status of CRM.

CRM dimensional improvement efforts Leverage analysis of CRM was conducted to observe its role in determining the sustainability of management. Changes in the value of root mean square (RMS) between the attributes when all attribute in the MDS analysis were used to identify the attributes that required improvements (Figure 4) to achieve an effective CRM. Improvement efforts for each

Table 2 Status category of coral reef management

Index	Management category
< 24.9	Poor
25 – 49.9	Insufficient
50 –74.9	Adequate
> 75	Good

Table 3 Statistical values of MDS analysis

Statistical value	Dimensional integration	Ecology	Socio - economic	Technology	Institutional
Stress	0.12	0.13	0.13	0.18	0.14
R^2	0.96	0.96	0.95	0.93	0.95
Number of iteration	2	2	2	3	3

dimension are provided in detail below.

Ecological dimensions Leverage analysis showed that the attributes of coral coverage, reef fish species diversity, climate, endemic species and sediments showed high levels of sensitivity in determining CRM (Figure 4A). Among the important factors that were affecting the coral reef ecosystem, temperature and sedimentation were considered as the major factors in controlling the growth of corals. Temperatures measured in this study ranged 29.4–32.50 ˚C. Gandi and Bawole (2009) report that water mass of Cenderawasih Bay show the existence of water mass of South Pacific Ocean which has a temperature of 28.42–29.96 ˚C with maximum surface temperature of 29.96 ˚C. It was also reported that the phenomenon of Cenderawasih Bay temperature was irregular with an average temperature of 29.65 ˚C due to the morphological structure of semi-enclosed bays.

Effect of temperature rise due to global warming that hit Indonesia in 1998 had resulted in the occurrence of coral bleaching that resulted in a 90–95% mass coral mortality (Suharsono 1999). During coral bleaching events, the average surface temperature of the water around the Thousand Islands was 2–3 ˚C above the normal temperature. Temperature of 18 ˚C at a certain time period was identified as the minimum sea water temperature that is functional for corals to live normally (Veron & Minchin 1992). Changes of 1–2 ˚C of sea temperatures allowed the reefs to begin adapting to the environment (Middlebrook *et al*. 2008).

Sedimentation can be derived from the flow of water into the river as a result of upper land clearing. There is a big river that channelled into Cenderawasih Bay carrying sediment loads. The Total Suspended Solid (TSS) was quite high (1.10–5.64 mg ℓ^{-1}) and were generally found in waters adjacent to the settlements (Rumberpon, Yopmeos, Manu Bay, Aiwori Peninsula, and Miyei). In 2010, the occurrence of big flood has caused a mass coral mortality in the Wondama Bay. The low salinity, high suspended solids, and nutrient-rich waters around the reefs had for some period destroyed the reefs around Miyei, Wasior, and Dotir regions. The main effects of increased nutrient-rich sediments on coral reefs have also been reported in Great Barrier Reef of Australia (Furnas & Mitchell 2001; Brodie *et al*. 2003; McKergow *et al*. 2005) and the Grand Canyon of America (Hughes *et al*. 2007). Fabricius (2005) discovers that surface flow had direct influence on the corals such as on: coral growth and survival, coral reproduction and recruitment, and organisms that interact with the reefs. Researchers found that sea water quality parameters such as dissolved oxygen, inorganic nutrients, increased particulate

Table 4 Differences of management index between MDS and Monte Carlo

Management Dimensions	Management Index		Difference
	MDS	Monte Carlo	
Ecology	71.47	69.91	1.56
Socio-economic	63.23	62.00	1.23
Technology	38.80	39.25	0.45
Institution	49.26	49.23	0.03

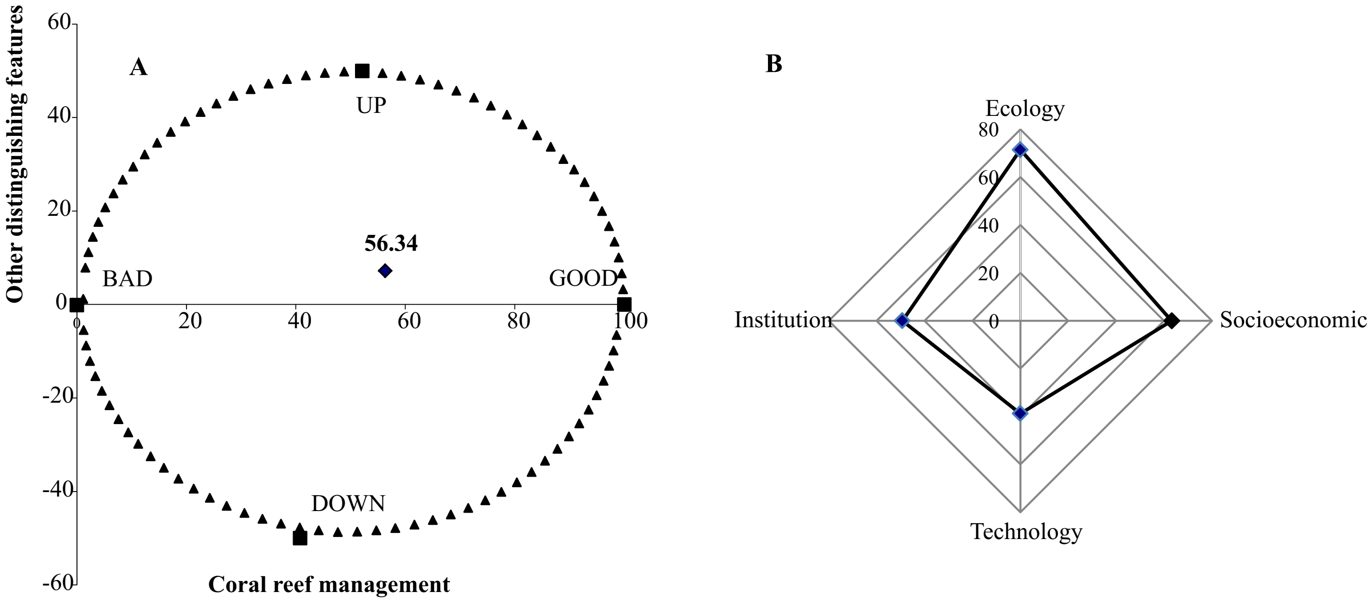

Figure 2 MDS analysis showing coral reef ecosystem management status (A) and inter-dimensional integration (B). Management status (♦), main guideline (■), additional guideline (▲).

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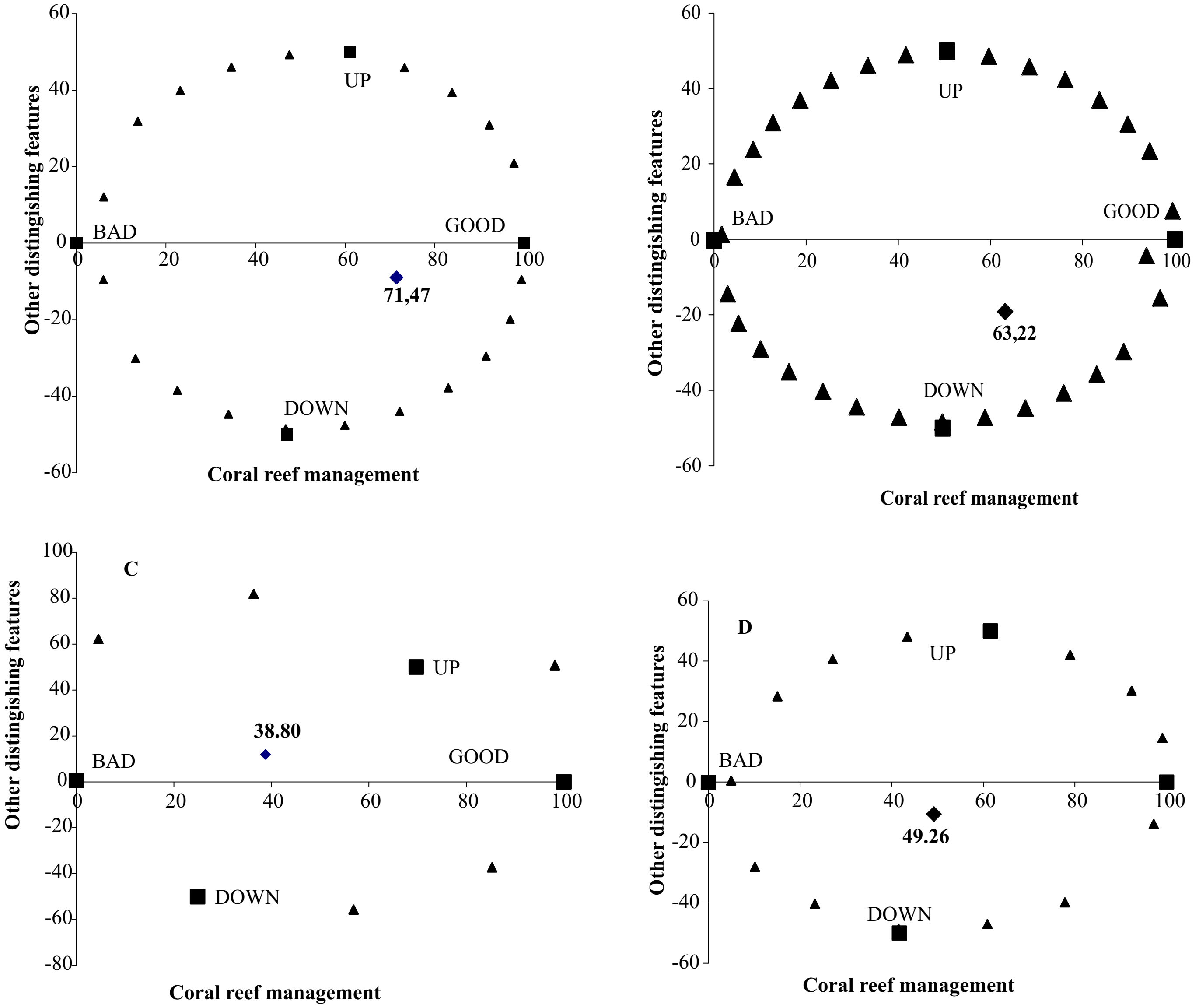

Figure 3 MDS analysis showing ecological dimensional based CMR management (A), Socio-economic dimension (B), technological use dimension (C) institutional dimension (D). Management status (♦), main guideline (■), additional guideline (▲).

organic matter, sediment reduction and increased clarity were all factors that simultaneously affected reefs condition.

The highest percentage of live coral coverage (78.2%) indicating a good condition of coral reef island was found in South-eastern Purup Island (78.2%), with low composition of benthic coverage (dead coral, algae, other fauna and abiotic). This showed that almost all shallow waters (1–10 m) were covered with live corals. Observations showed that local fishing activities contributed to coral death through the removal of anchors and destructive fishing gears. According to Lazuardi (2006), CBNP had a coral coverage percentage of 36.27% with 45% coral mortality index. Damages to the reefs were due to the pressures of reef fishing, sedimentation, fishermen anchors, coral bleaching, and water runoff from inland.

There were 9 research stations with good coral reefs condition with live coral coverage of 55.16–72.6% inhabited by about 84–123 species. Based on the percentage of live coral coverage, it could be concluded that out of the 17 research stations, 53% were in the range of good to excellent condition, 35% was categorized good, and 12% poor. These showed that the condition of coral reef ecosystems in CBNP is considered in good condition, although it is experiencing high environmental pressures. This study supported the previous research results that concluded the condition of coral reefs in Cenderawasih Bay as moderate to good with live coral percentage > 50% in almost all the studied sites, and the ratio of live to dead coral were 5:1 indicating a high presence of live corals (Turak & DeVantier 2006). Other indications include dead corals, turf algae and coral reef that previously suffered damages as the result of both natural and mechanical pressures (currents and

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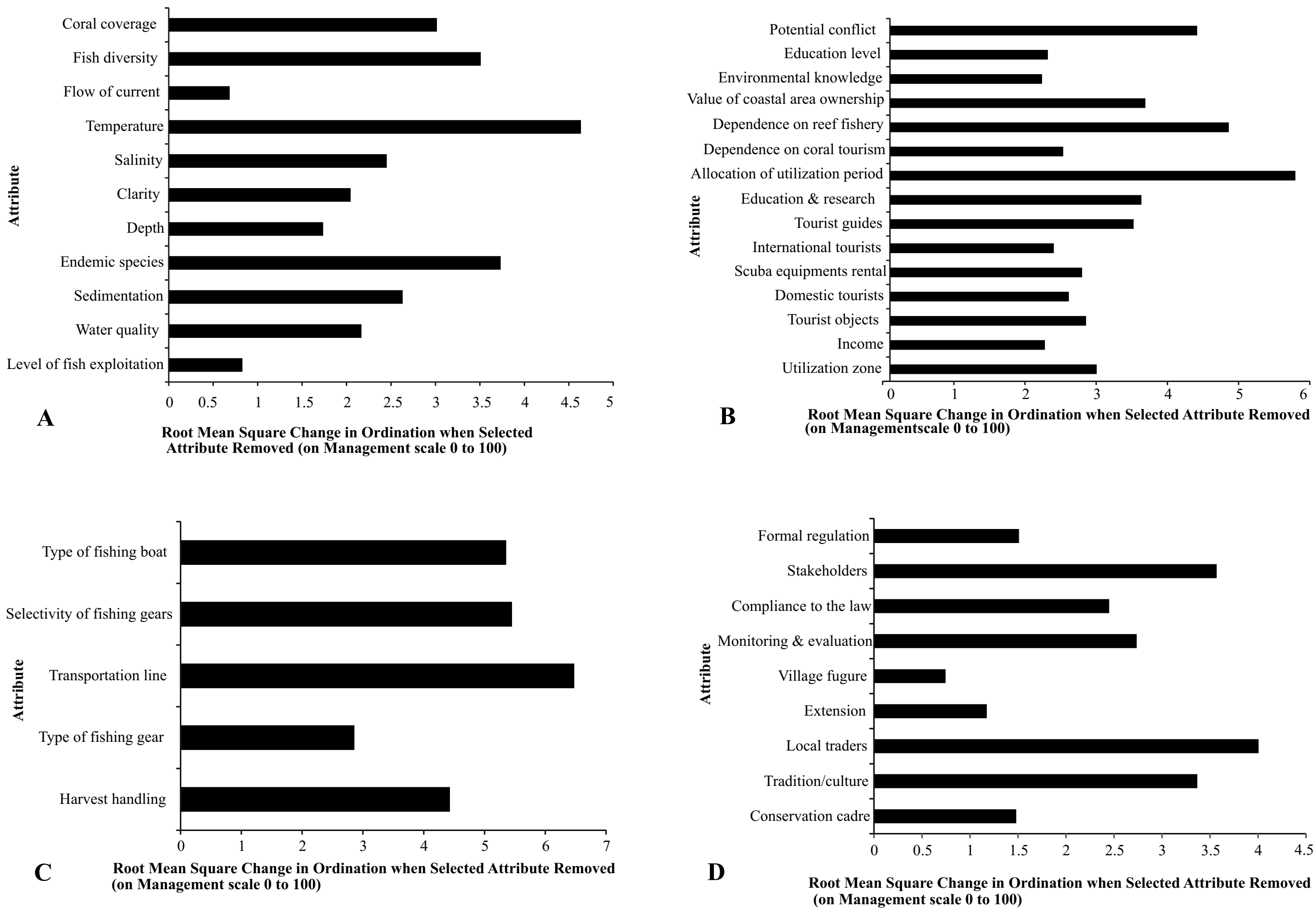

Figure 4 Leverage analysis showing roles of dimensional attributes of ecology (A); socio-economic (B), technology (C), and institutional (D).

waves, earthquakes), or due to human activities (fishing). Reef damages in Cenderawasih Bay were caused by the population boom of *Acanthaster planci* (Turak & DeVantier 2006).

Judging from the eco-biological aspects, Cenderawasih Bay has a high endemic species. Allen and Erdmann (2009a) report a total of 718 reef fish species in Cenderawasih Bay including new species, *Chromis unipa* (Allen & Erdmann 2009b), *Chrysiptera arnazae* (Allen *et al.* 2010), *Columia ellperinae,* and C. *papuensi* (Allen & Erdmann 2010). The highest fish diversity sites were observed in Purui Island, Ayemi Peninsula, and Matas Island with a total of 126–139 fish species. The high diversity of species in the 3 locations was possible due to the high percentage of coral cover. Unfortunately, these areas are facing high occurrences of commercial fishing for *Lates* sp., *Ephinepelus* sp., *Chelinius undulatus*, *Letrinus* sp., caught by fishermen from outside CBNP where catches were often made in the no-take zone (core zone).

Socio-economic dimension Leverage analysis showed that potential conflict, ownership of coastal land, dependence on reef fisheries and allocation of time were attributes with high sensitivities (Figure 4B). This result was not too surprising since coral reef ecosystem could provide the necessary daily needs of the community. Collections of shellfish, fishing with nets, fishing with tuba root (*Derris* sp.), and coral reefs biota, comprised major activities found at Cenderawasih Bay. The impacts of local people's activities on the condition of coral reefs were very high, due to lack of public understanding on the importance and benefits of coral reef ecosystems. Fishing was often done with bombing and anesthetic techniques. Fish bombing was reportedly in the Philippines (White *et al*. 2000) and in Indonesia (Cesar *et al*. 1997; Pet-Soede *et al*. 1999) where such practices were found in almost all regions in Indonesia. Losses due to fish bombing for 20 years were estimated at US $ 306,900 km^{-2} of coral reefs (Pet-Soede *et al*. 1999). The main reason for such destructive fishing techniques were basically related to household economic interests (Pet-Soede *et al*. 1999; White *et al*. 2000).

Technological dimensions Leverage analysis showed that the attributes with high sensitivity were type of gear, gear selectivity, transportation line, and handling of harvests/catches (Figure 4C). As a marine protected area, it is necessary to regulate transportation line with regard to cargo ships, passenger ships, and other ships used by the public. One basic problem was the transportation line of passenger/cargo ships that passed through the core zone which might cause adverse impacts on the corals. This was also compounded by the frequency of ship throwing wastes (organic and non-organic) while passing through the waters of the Cenderawasih Bay. Spatial planning of the coastal and marine areas must be done to provide an appropriate transportation line for each user of ocean transportation services. Pressure on catches due to non selective gear would also damage coral reef ecosystems. Operation of basic gill nets around the coral reefs was not a good choice. The use of bombs and toxic materials were often found in waters around Cenderawasih Bay. The environmental impacts of artisanal fishing gear on coral ecosystems have been studied in recent decades such as in Indonesia (Edinger *et al*. 1998; Wiadnya *et al*. 2005); Kenya (Mangi & Roberts 2006), and Caribbean (Hawkins & Roberts 2004). Overcoming such impacts required necessary regulations on gear restrictions, destructive fishing gear and mesh settings (Pauly *et al*. 2002) to strengthening the protected areas adjacent to fish harvesting areas (Roberts *et al*. 2001).

Institutional dimension Leverage analysis showed that stakeholders, compliance to rules, monitoring and evaluation, local traders and culture/tradition were attributes of institution having high sensitivity (Figure 4D). Institution is a place where people can interact, particularly in ensuring the flow of information and services. Local traders were necessary considering the limited market access in several areas of Cenderawasih Bay. They were required to ensure the availability of food as well as place where people could sell their products (agriculture and fishery). Local culture/traditions in exploiting coral reefs could be categorized as good management due to the existence of local wisdom in utilizing coral reef resources (sea cucumbers and lobsters).

Stakeholders were an essential dimension of sustainability of protected area governance (Bawole *et al*. 2011; Bawole 2012). Community involvement is very important in planning, design, development, and management of MPAs (Mascia 2003), especially when the stakeholders are expected to support and assist the management process. Stakeholder involvement at the early stages of planning create a sense of belonging and commitment in the implementation of management activities (Cinner *et al*. 2005; Granek & Brown 2005). Monitoring and evaluation were conducted to assess the performance of management process although its implementation is only a procedure or formality in the administrative activities (Bawole *et al*. 2011). Hence, management activities have not shown any impacts on increasing fish biomass, as well as improving environmental conditions and welfare.

An interesting result related to integrating CRM dimensions was that although conservation instruments have evolved in recent years nevertheless many weaknesses were still found. Government instability, poverty, population growth, limited monitoring and law violence still comprised some major problems for marine conservation in Indonesia. Knowledge transformation to the local communities still faced many challenges and obstacles due to various perceptions and cultures. Issues of training, local capacity building, and inadequate infrastructures remained the problems for the implementation of management activities. Limitations of science and technology were often the limiting factors in conservation. When scientific information is limited, but the need for conservation is urgent, alternative strategies remained a powerful option in addressing management issues (Bawole *et al*. 2011). Adaptive management is necessary in addressing socio-economic problems while maintaining the sustainability of ecological resources (Olsson *et al*. 2004; Allen *et al*. 2010). Adaptive management is conducted in collaboration related to the problem solving process involved in the distribution of power management at the institutional level (Carlsson & Berkes 2005). Each location has unique culture, socio-economic, and local knowledge necessary for evaluation, design, and implementation activities in order to achieve successful CRM strategy.

Conclusion

Sustainability analysis showed that the current state of the aggregates for all management dimensions was fairly sustainable, although technological and institutional dimensions should be further observed. Improved attributes for each dimension based on the leverage analysis should be observed to optimize CRM efforts in ensuring the functions and dynamics of ecosystems. Integration of the dimensions of ecology, socio-economic, technology, and institution were the main complementary aspects between dimensions at all phases of CRM. This would determine all processes that associated with the management phase and produce reference for a successful conservation management.

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