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Research Articles

Understanding Enabling Factors for Community-Led Coral Reef Health Monitoring and Early Warning System through Participatory Action Research

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ABSTRACT

Terumbu karang menghadapi tekanan dari perubahan iklim dan berbagai faktor lainnya yang membuatnya berisiko mengalami penurunan daya tahan. Kerentanan yang meningkat ini meningkatkan kemungkinan mencapai titik kritis dengan guncangan atau stresor berikutnya. Mengidentifikasi indikator peringatan dini untuk titik kritis sangat penting untuk manajemen terumbu karang yang proaktif. Oleh karena itu, penelitian ini bertujuan untuk memahami parameter kesehatan terumbu karang yang dianggap penting dan layak untuk dikumpulkan oleh pemangku kepentingan setempat, serta mengidentifikasi faktor-faktor yang memfasilitasi implementasi sistem pemantauan dan peringatan dini kesehatan terumbu karang yang berbasis masyarakat di komunitas nelayan. Pendekatan yang digunakan adalah Penelitian Tindakan Partisipatif. Hasil penelitian menunjukkan bahwa terdapat dua belas parameter prioritas yang dianggap penting oleh komunitas setempat dan dapat dikumpulkan oleh pemangku kepentingan setempat (komunitas setempat, perguruan tinggi setempat, dan organisasi non-pemerintah setempat). Parameter yang teridentifikasi meliputi: pemutihan karang, visibilitas, suhu, pH, oksigen terlarut, salinitas, arus, persentase tutupan karang, komunitas ikan, tutupan dan komposisi kanopi makroalga, komposisi benthos, dan plankton. Model struktural interpretatif dan analisis MICMAC menunjukkan bahwa ada sembilan faktor yang mendukung pengembangan sistem pemantauan dan peringatan dini kesehatan terumbu karang yang dipimpin oleh masyarakat, yaitu motivasi tim, pelatihan dan kapasitas tim, koneksi dengan pemerintah, koneksi dengan perguruan tinggi, fasilitasi oleh LSM, peraturan pendukung, dana operasional, akses ke peralatan, dan operasi serta pemeliharaan peralatan. Faktor motivasi tim memiliki kekuatan pendorong dan ketergantungan yang kuat, menjadikannya faktor paling penting untuk dikelola karena tindakan pada faktor ini akan berdampak pada faktor lainnya.

Kata kunci: model structural interpretatif; analisis MICMAC; titik kritis

ABSTRAK

Coral reefs are under pressure from climate change and various factors, putting them at risk of a decline in resilience. This heightened vulnerability increases the likelihood of reaching a tipping point with the next shock or stressor. Identifying early warning indicators for tipping points is crucial for proactive coral reef management. Therefore, this study aims to comprehend the coral reef health parameters considered important and feasible for collection by local stakeholders, as well as identify factors facilitating the implementation of a community-based monitoring and early warning system in a fishers-dominated community. The approach used was Participatory Action Research. The results reveal twelve priority parameters deemed necessary by the local community and feasible for collection by local stakeholders, including the local community, university, and non-governmental organization. The identified parameters are: coral bleaching, visibility, temperature, pH, dissolved oxygen, salinity, current, coral percent cover, fish community, macroalgal canopy cover and composition, benthic composition, and plankton. Interpretive structural model and MICMAC analysis show nine enabling factors supporting the development of a community-led coral reef health monitoring and early warning system. These factors include team motivation, training and team capacity, connection with government, connection with university, facilitation by NGOs, supporting regulations, operational funds, access to equipment, and operation and maintenance of equipment. Team motivation stands out as the most influential factor, with strong driving power and dependence, making it crucial to manage as actions on it will have ripple effects on other factors.

Key words: interpretive structural model; MICMAC analysis; tipping point

INTRODUCTION

The ecological and economic services provided by coral reefs are vast, extending their impact globally, nationally, and locally. Coral reef is globally estimated to be approximately a trillion-dollar economic asset (Hoegh-Guldberg, 2015) with US$ 36 billion from tourism (Spalding et al., 2017) and US$ 130 billion from flood protection (Beck et al., 2018). Costanza et al. (2014) conducted an evaluation indicating that the average contribution of coral reefs is approximately $350,000 per hectare per year.

Indonesia, located in the Coral Triangle region, is home for 16% of the global total reef area where the reefs are recognized as being amongst the most diverse ecosystems in the world (Burke et al., 2012). Coral reefs flourish and attain peak biodiversity in the Coral Triangle region, encompassing areas such as Sulawesi, Maluku, Halmahera, West Papua, Raja Ampat Islands, Aru Islands, Kei Islands, East Nusa Tenggara, and West Nusa Tenggara and Bali (Hadi et al. 2020). With almost 25% of its inhabitants reside along the coast within a 30 km radius of coral reef, Indonesia has the largest reef-associated human population globally (Razak et al., 2022). Unfortunately, coral reefs globally, including those in Indonesia, have suffered severe damage due to anthropogenic stressors such as pollution, eutrophication, overfishing, destructive fishing practices, ocean warming and acidification, along with mass bleaching linked to climate change (Hadi et al., 2020; Hughes et al., 2017). In Indonesia, the Lesser Sunda area especially Bali and West Nusa Tenggara were most suffering during the bleaching event in 2016 (Hadi et al., 2020).

As of 2019, around 69.15% ± 0.29 of the reefs had less than 50% coral cover, classified as poor and fair reefs, and exhibited fluctuating trends. These reefs, while providing space for coral recruits to attach and grow, are considered unstable and highly susceptible to various stressors (Hadi et al., 2020). Researchers have highlighted the urgent need for accurate and actionable monitoring data as coral reef systems are facing imminent risk of collapsing within a few decades (Obura et al., 2019; Razak et al., 2022). The monitoring of coral reef status and trends is crucial for informing science, management, and policy decisions (Obura et al., 2019). A lack of appropriate and standardised monitoring and reporting is also a major challenge in restoration projects (Boström-Einarsso, 2020). A systematic review by Razak et al. (2022) indicated that projects related to coral reef restoration in Indonesia frequently lack coordination with broader networks of restoration practitioners or scientists. Alarmingly, according to the review, only 16% of the identified projects incorporated a post-installation monitoring framework.

Coral reefs, along with many ecosystems under stress from climate change and various factors, are at risk of decline in resilience, making it more susceptible to crossing a tipping point with the next shock or stressor (Brandl and Bellwood 2014). Selkoe et al. (2015) suggested seven principles for managing marine ecosystems prone to tipping points. One of the principles is that early warning indicators of tipping points enable proactive response. Identifying reliable leading indicators of tipping points is a promising and evolving area of research (Dakos et al. 2015). However, this field is still in its early stages and faces challenges, particularly in terms of data requirements (Selkoe et al. 2015).

Community-based monitoring should be better supported and integrated with more detailed monitoring programs to extend data generated for management and for its role in building public support for coral reef conservation (Obura et al., 2019). When high-quality time series chronicling historical ecosystem tipping points exist, they can be mined to identify species or system traits that changed in advance of the ecosystem shift and might serve as early-warning indicators of a future tipping point (Selkoe et al., 2015). Therefore, this study aims to understand the factors that facilitate the implementation of a community-based monitoring and early warning system for coral reef health in a fishers-dominated community. The approach used was Participatory Action Research, aligning with recommendations from Obura et al. (2019). These recommendations emphasize the importance of investing in methods, instruments, and data applicable to local stakeholders and managers for locally-relevant research and management. Furthermore, they advocate for sustained training to bridge capacity gaps in developing countries, empowering local stakeholders with the knowledge and infrastructure to generate, comprehend, and utilize available data.

This study will specifically focus on Labuhan Bajo Village in the Sumbawa District, West Nusa Tenggara Province, Indonesia. The community group participating in the research is known as Kabete Bajo, established through the Decree of the Head of the Marine Affairs and Fisheries Agency of Sumbawa District Number 54/2021 (Hidayati et al., 2022). This group's name is derived from the three islands around the village: Keramat Island, Bedil Island, and Temudong Island. The establishment of Kabete Bajo was driven by the goal of protecting and preserving natural resources in the waters surrounding Keramat, Bedil, and Temudong Islands, including coral reef ecosystems, seagrass beds, and mangroves. The intention is to manage these areas as marine tourism attractions to bring economic benefits to the local fishing community.

While community-based marine tourism is not fully realized, the community has initiated various coral restoration methods, including concrete structures, iron structures, spiderweb structures, and coconut shells. Therefore, implementing coral reef health monitoring and an early warning system is expected to empower local stakeholders to take necessary measures for the conservation of the ecosystems they depend on. Simultaneously, it will demonstrate their active participation in sustainable tourism once it becomes fully established.

This case study will provide insight into the feasibility and challenges associated with establishing clear objectives and implementing long-term community-led monitoring programs and an early warning system. The findings are anticipated to provide valuable information for informing policy, guiding management interventions, and contributing to effective coral reef conservation in the region.

METHOD

Research Site

This research was carried out from October 2022 to November 2023 in Labuhan Bajo Village, Sumbawa District, West Nusa Tenggara Province, Indonesia (8°24'31.6"S 117°05'23.1"E). The major source of income here is fishing. The coastal village, spanning 20 km², is inhabited by 1,924 people (BPS Kabupaten Sumbawa, 2019). The village is situatied in proximity to the 1955.55 hectares Kramat, Bedil and Temudong Conservation Area which was enacted through the Minister of Marine Affairs and Fisheries Decree Number 104 Year 2023) comprising a core zone spanning 110.18 hectares, a utilization zone spanning 1844.17 hectares, and other zone around 1.20 hectares.

Research Procedure

This study used the Participatory Action Research (PAR) approach. Participatory Action Research is a methodology aimed at producing knowledge-for action and knowledge-through action, serving the specific goals of communities and typically involves a collaborative effort between a community with firsthand experience of the issue and professional researchers, often affiliated with universities, who contribute relevant knowledge, skills, resources, and networks (Cornish et al., 2023). Local stakeholders involved in this research included the village government, a community group, university experts (specializing in coral reefs, seagrass, and monitoring), and a Non-Governmental Organization.

According to Savin-Baden and Wimpenny (2007), the fundamental procedures of PAR encompass "planning a change with the community; acting and observing the process and consequences; reflecting on their processes and consequences; and further cycles of planning, acting, and reflecting" (p. 335). PAR is guided by four principles, as outlined by Cornish et al. (2023): the appreciation of expertise derived from experience; the application of knowledge in action; research as a transformative process; and collaboration facilitated through dialogue. The research procedure is presented in Figure 1. Data collection and analysis method is described in Table 1.

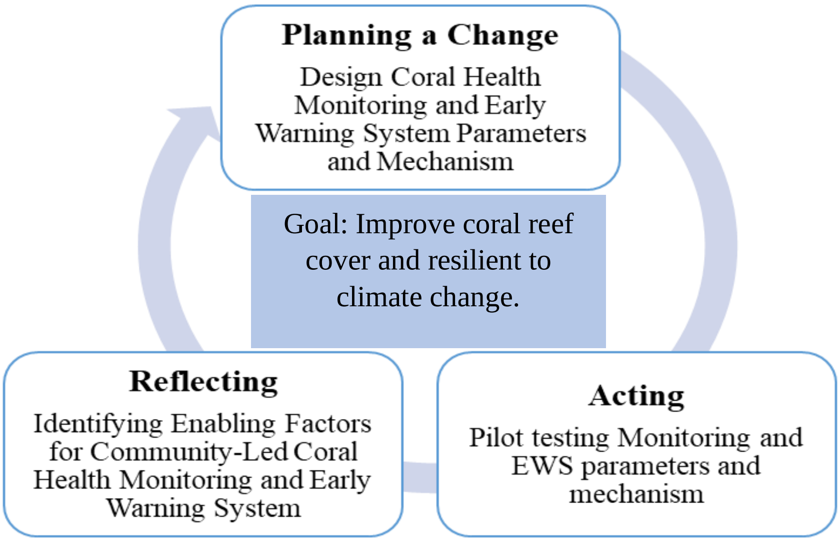

Figure 1. Research Procedure

Table 1. Data collection and analysis method

PAR Procedure	Data collection method	Data gathered	Data analysis
Planning	Half-day workshop. Participants: experts from university (5 people), Head of Labuhan Bajo village (1), Secretary of Labuhan Bajo Village (1), Kabete Bajo group (7 people), NGO (5 people).	The feasibility of coral reef health parameters -based on Essential Ocean Variables (GOOS, 2022), Socio-economic parameters (Hill & Wilkinson, 2008) and in the Government Regulation (GoI, 2021)- to be monitored by community, university, internet, and cannot be collected with the current capacity.	Content analysis of the workshop results. The feasibility analysis considered (i) likelihood of access to equipment, (ii) likelihood of capability to use the equipment, and (iii) likelihood of capacity to analyze the data.
Planning	One-day workshop. Participants: Kabete Bajo group (7 people), NGO (5 people).	Priority parameters for local community.	Content analysis of the workshop results.
Acting	Eight-days training for the Kabete Bajo group.	Feasible community-based coral reef health monitoring and early warning system mechanism.	Before and after training evaluation results.
Reflecting	Three-days workshop: Participants: Kabete Bajo group (7 people), NGO (5 people), academics (1 person).	Enabling and limiting factors for community-based coral health monitoring and early warning system.	Interpretive Structural Model (ISM) and MICMAC Analysis. independent factors.

ISM is a recognized methodology for discerning relationships among specific elements that characterize a problem or issue (Attri et al., 2013). The development of the Interpretive

Structural Model (ISM) followed the steps outlined in the works of Attri et al. (2013), Talib & Faisal (2016), and Sushil (2012) as follows.

I. Identify the elements which are relevant to the issue. In this study, enabling and limiting factors are identified from the data collected from the workshop with key stakeholders.

II. Develop a structural self-interaction matrix (SSIM) of elements. This matrix indicates the pair-wise relationship among enablers factors of the system. This matrix is checked for transitivity. Four standardized symbols were used to denote the relationship between the two enablers under consideration. The symbols are:
   a. V: enabler i will help achieve enabler j;
   b. A: enabler j will help achieve enabler i;
   c. X: enablers i and j help each other;
   d. O: enablers i and j are unrelated.

   i represents enablers arranged in each row, while j represents enablers arranged in each column.

   At this stage, contextual relationship is obtained from discussion with relevant key stakeholders.

III. Develop a reachability matrix from the SSIM. The SSIM format is transformed into the reachability matrix format by substituting v, a, x, and o by binary numbers ‘1’ or ‘0’. This transformation is carried out as per the standard ISM rules as follows:
   a. If the (i,j) entry in the SSIM is a V, the (i,j) entry inthe reachability matrix becomes 1 and the (j,i) entry becomes 0.
   b. If the (i,j) entry in the SSIM is anA, the (i,j) entry inthe reachability matrix becomes 0 and the (j,i) entry becomes 1.
   c. If the (i,j) entry in the SSIM is an X, both the (i,j) entry and the (j,i) entry of the reachability matrix become 1.

IV. If the (i,j) entry of the SSIM is a 0, then both the (i,j) and (j,i) entries of the reachability matrix become 0. Partition the reachability matrix into different levels.

V. Convert the reachability matrix into conical form.

VI. Draw digraph (directional graph) based on the relationship given in Reachability Matrix and remove transitive links.

VII. Convert the resultant digraph into an ISM based model by replacing element nodes with the statements.

VIII. Undertake MICMAC Analysis. MICMAC stands for Matrice d’Impacts croises-multiplication appliqúe an classment (cross-impact matrix multiplication applied to classification) (Godet, 1986). MICMAC analysis will classify the enablers into four categories i.e., autonomous factors, linkage factors, dependent factors and independent factors. Autonomous factors have weak drive power and weak dependence power. They are relatively disconnected from the system (Attri et al., 2013).

RESULTS AND DISCUSSION

Planning a Change: Designing the parameters for coral reef health monitoring and early warning system.

The parameter "hard coral cover" has traditionally been the standard metric for reporting coral reef health (Tittensor et al., 2014). However, coral reefs constitute intricate ecosystems with diverse biological diversity, varying composition and properties of coral communities, recovery potential, and involvement in functional, trophic, biogeochemical, and physical processes (Obura et al., 2019). Relying solely on a single variable is deemed insufficient for a comprehensive understanding of reef health (Diaz-Perez et al., 2016).

To enhance and advance global ocean observing systems, working groups under the Global Ocean Observing System, a platform of the United Nations Educational, Scientific and Cultural Organization's Intergovernmental Oceanographic Commission (UNESCO-IOC), have developed Essential Ocean Variables (EOVs), encompassing physical and biogeochemical, biological, and ecosystem parameters of the ocean. This initiative aims to provide a more holistic and nuanced perspective on the health and dynamics of ocean ecosystems.

In addition to referring to the global ocean observing system (see specification sheet at: www.goosocean.org/eov), coral reef health parameters (Table 2) were also identified from the Ecological Monitoring of Coral Reefs (Hill and Wilkinson, 2004), and Government Regulation of the Republic of Indonesia 22/2021 on Implementation of Environmental Management and Protection. The parameters were subsequently categorized based on their feasibility, as outlined in Tables 3, 4, and 5, for collection purposes: (i) by the local community, (ii) by the local university, (iii) from the internet, and (iv) deemed unattainable with the current capacity of local stakeholders. This categorization was determined by evaluating the likelihood of access to equipment, capability to use the equipment, and capacity to analyze the data. Certain parameters, such as temperature, salinity, particulate matter, and hard coral cover, are found across all three lists. Additionally, several parameters are shared between two of the lists.

Table 2. Coral health parameters

Parameters	Essential Ocean Variables	Ecological Monitoring of Coral Reefs (Hill and Wilkinson, 2004)	Government Regulation of the Republic of Indonesia 22/2021
Sea surface level	√		
Sea surface temperature	√	√	√
Subsurface temperature	√	√	√
Surface current	√	√	
Subsurface current	√	√	
Sea surface salinity	√	√	
Sub surface salinity	√	√	√
(Dissolved) Oxygen	√		√
Nutrients	√		√
Particulate matter	√	√	√
Dissolved organic carbon	√		
Plankton diversity	√		√

Parameters	Essential Ocean Variables	Ecological Monitoring of Coral Reefs (Hill and Wilkinson, 2004)	Government Regulation of the Republic of Indonesia 22/2021
Fish abundance and distribution	√	√	
Marine turtles, birds, mammals abundance and distribution	√		
Hard coral cover and composition	√	√	√
Macroalgal canopy cover and composition	√		
Invertebrate abundance and distribution	√	√	
Visibility		√	√
Debris			√
Ph		√	√
Biological oxygen demand (BOD)			√
Coral bleaching		√	
Coral disease		√	
Depth, bathymetry, coral profile		√	

Table 3 outlines seventeen Essential Ocean Variables (EOV) and their respective data collection methods based on the Global Ocean Observing System. This study reveals that, at present, the local university can collect data for most parameters, with the exceptions of five parameters, namely, sea surface level, subsurface temperature, subsurface current, nutrients and dissolved organic carbon due to the unavailability of specific equipment. However, if such equipment becomes accessible, the local university would be capable gathering information on these specific parameters. Global sea surface temperature data, on the other hand, can be sourced from the internet. Regarding the local community, their capability extends to collecting seven variables which can be collected with portable equipment. According to Obura et al. (2019), three EOVs provide a robust description of reef health: hard coral cover and composition, macro-algal canopy cover, and fish diversity and abundance.

Table 3. Essential Ocean Variables (EOV) as listed by the Global Ocean Observing System

Parameters	Method	i*	ii*	iii*	iv*
Sea surface level	Water level data logger				√
Sea Surface Temperature	Thermometer		√	√ www.ospo.noaa.gov	
Subsurface temperature	Temperature data logger				√
Surface current	Current meter		√		
Subsurface current	Subsurface current meter				√
Sea surface salinity	Refractometer	√	√		
Subsea surface salinity	Refractometer	√	√		

Parameters	Method	i*	ii*	iii*	iv*
(Dissolved) Oxygen	DO meter	√	√		
Nutrients	Spectrophotometry				√
Particulate matter	TSS meter	√	√		
Dissolved organic carbon	Total Organic Carbon Analyzer				√
Plankton diversity	Plankton net, microscope		√		
Fish abundance and distribution	Diving, Underwater visual census	√	√		
Marine turtles, birds, mammals abundance and distribution	Visual census		√		
Hard coral cover and composition	Diving, Underwater Photo Transect	√	√		
Macroalgal canopy cover and composition	Diving, Underwater Photo Transect		√		
Invertebrate abundance and distribution	Diving, Underwater Visual census	√	√		

* i = local community; ii = local university; iii = internet; and iv = cannot be collected with current capacity.

Table 4 shows relevant parameters from Government Regulation of the Republic of Indonesia 22/2021, Appendix VIII on Marine Water Quallity Standard for Marine Biota. Parameters that require expensive laboratory analysis were excluded from discussion during the workshop. Most of the parameters are the same as the EOV except for the pH, debris, and biological oxygen demand.

Table 4. Water Quality Parameters for Marine Biota based on Government Regulation of the Republic of Indonesia 22/2021

Parameters	Method	i*	ii*	iii*	iv*
Visibility	(*Secchi disk*) Slowly lower the Secchi disk until it is no longer visible	√	√		
Total Suspended Solid	TSS Meter (Portable digital equipment)	√	√		
Sea Surface temperature	Thermometer	√	√	www.ospo.noaa.gov	
Subsurface Temperature Data series	Temperature data logger				√
Debris	Visual	√	√		
pH	pH meter (Portable digital equipment)	√	√		
Salinity	Refractometer (Portable digital equipment)	√	√		
Dissolved Oxygen	DO meter (Portable digital equipment)	√	√		
Biological Oxygen Demand	BOD meter (Portable digital equipment)	√	√		
Ammonia	Spectrophotometry				√
Nitrate	Spectrophotometry				√
Phosphate	Spectrophotometry				√

Parameters	Method	i*	ii*	iii*	iv*
Sulfide	Spectrophotometry				√
Coral percent cover	Diving, Underwater Photo Transect	√	√		

* i = local community; ii = local university; iii = internet; and iv = cannot be collected with current capacity.

Table 5 presents twelve ecological parameters related to coral health based on Hill and Wilkinson (2004). All these parameters are collectible by the local university. The local community has the capacity to gather most of the parameters, with the exceptions being coral disease, biomass and structure of fish population, depth, bathymetry, and reef profiles. Among the three lists utilized in this research, this is the only list that includes coral bleaching and coral disease—two parameters gaining increased attention as global mean temperatures are predicted to rise. Currently, coral bleaching stands as one of the foremost threats to coral reefs in the medium to long term (next 50 years) and other predicted impacts of global warming on reefs shows that an increase in the incidence and severity of storms, along with elevated concentrations of CO_2 in seawater, leading to reduced rates of coral calcification and increased fragility in colonies (Wilkinson et al., 2003).

Table 5. Parameters Based on Methods for Ecological Monitoring of Coral Reefs (Hill and Wilkinson, 2004)

Parameters	Method	i*	ii*	iii*	iv*
Coral Percent cover	Diving, Underwater Photo Transect	√	√		
Species or genus composition and size structure of coral communities	Diving, Line Intercept Transect		√		
Coral Fragment	Diving, Underwater Photo Transect	√	√		
Biomass and structure of fish populations	Diving, Underwater Visual census		√		
Populations of organisms of special interest	Diving, Underwater Visual census	√	√		
Coral bleaching	Diving, Underwater Photo Transect	√	√		
Coral disease	Diving, Underwater Photo Transect		√		
Depth, bathymetry and reef profiles	Marine Acoustics/ Echosounder		√	https://tanahair.indonesia.go.id/demnas/	
Currents	Current meter		√		
Temperature	Thermometer	√	√		
Water Quality the amount of sediments, nutrients and pollutants in the water to assist in assessing pollution.	Water quality checker	√	√		

Parameters	Method	i*	ii*	iii*	iv*
Visibility	Secchi disk	√	√		
Salinity	Refractometer	√	√		

* i = local community; ii = local university; iii = internet; and iv = cannot be collected with current capacity.

Drawing from the results of the workshop, training, and feasibility analysis of various parameters, the local community and experts have collaboratively identified a set of key parameters essential for monitoring and establishing an early warning system in the context of climate change vulnerability and resilience. The finalized list is presented in Table 6.

Table 6. Priority Parameters to Improve Understanding on Coral Vulnerability and Resiliency to Climate Change

Parameters	Method	Feasibility
Coral Bleaching: Species or genera of corals showing bleaching and the amount of bleaching in the coral colonies.	-Underwater photo transects -Bleaching alert products were developed by the National Oceanic and Atmospheric Administration (NOAA) Coral Reef Watch Program (http://coralreefwatch.noaa.gov/satellite/;	Color is one of the parameters that was repeatedly mentioned by the local community during workshop. Feasible to be conducted by the local community group in collaboration with local university following the stages of coral bleaching monitoring event as suggested by Obura et al. (2022).
Visibility: How far one can see under water (i.e. penetration of light for photosynthesis)	- Secchi disk - Slowly lower the Secchi disk until it is no longer visible	Equipment is easy to operate. Feasible to be conducted by the local community group.
Temperature: Measures of water temperature at different locations on coral reefs.	Thermometer (Portable digital equipment)	Feasible to be conducted by the local community using thermometer.
pH	pH meter (Portable digital equipment)	Feasible to be conducted by the local community using pH meter.
Dissolved oxygen	DO Meter (Portable digital equipment)	Equipment is easy to operate. Feasible to be conducted by the local community group.
Salinity	Salinometer (Portable digital equipment)	Feasible to be conducted by the local community using hand refractometer.
Current: General measures of current directions and speeds are important for predicting the fl ows of pollution or new larvae.	Current meter	Feasible to be conducted by the local community if the equipment is available.
Percentage cover: This measures the area of living corals and also	Diving, Underwater Photo Transect (Belt transect) (Hill and Wilkinson, 2004)	Data collection is feasible to be conducted by local community who are certified divers.

Parameters	Method	Feasibility
detects dead corals which may indicate stress.		
Biomass and structure of fish populations	Diving, Underwater Visual Census	Need more training on scientific scuba diving
Macroalgal canopy cover and composition	Diving, Underwater Photo Transect	Need more training on data analysis and differentiating algal from soft corals.
Benthic communities	General observation (Hill and Wilkinson, 2004)	Data collection is feasible to be conducted by local community who are certified divers.
Plankton	Plankton net, microscope	Data collection and analysis are feasible to be conducted by local university students.

Acting: Monitoring and Early Warning System Mechanism in the Research Site

The monitoring and early warning system mechanism was developed with a focus on the goal identified by the community. Through workshops and interviews, it became apparent that the local community perceives severe degradation of coral reefs near their village, attributing it to irresponsible behaviors, despite acknowledging that some areas with coral reefs remain in good condition, for example, in Bedil Island near the village (Himawan et al., 2021). Hence, the community's goal is to prevent further degradation of the remaining reefs and at the same time increasing coral percent cover through restoration efforts. To achieve the goal, the community-based monitoring and early warning system for coral reef health was established, encompassing both the natural reef ecosystems and areas where community-led restoration efforts were undertaken adjacent to the village (Figure 2a and 2b). The parameters and methods for both locations are the same as outlined in Table 6.

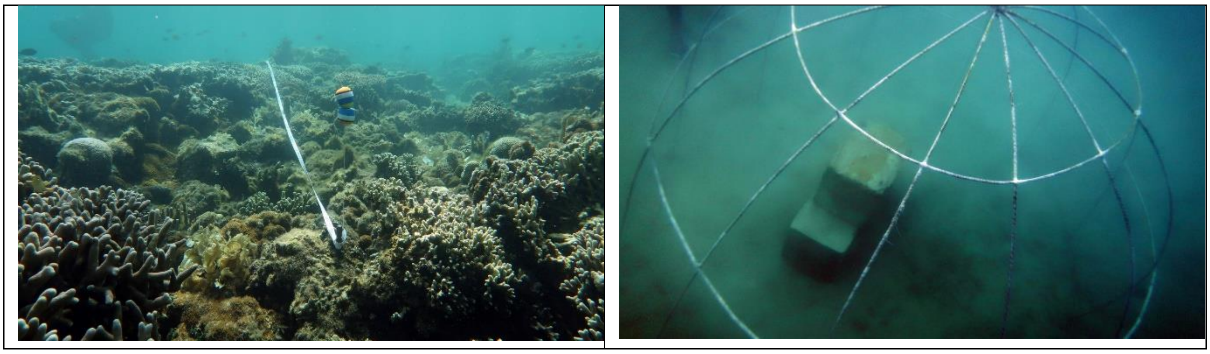

Figure 2. (a) Permanent transect in natural coral reef ecosystem, (b) Coral restoration structure in the research site

Monitoring is conducted on a monthly basis, with the Kabete Bajo Group collecting data on the listed parameters. In the natural ecosystem, monitoring is conducted using three permanent 50-meter belt transects (Figure 2a). For restoration site, monitoring is done by documenting the structure through photos and videos. The collected data are stored in a cloud data storage system, and subsequent analysis is carried out collaboratively by the Kabete Bajo Group, the local university, and the local Non-Government Organization. In addition to being utilized for management interventions, the data and the process are also intended to be used for raising awareness among the village community, other relevant stakeholders, and the general public. To raise awareness at the village community, a manual display for each parameter is installed in the Marine Information Center at the village (Figure 3). To engage relevant stakeholders and the general public, the local community established social media accounts dedicated to sharing updates on monitoring and early warning system activities.

Figure 3. Manual Data Visualization in the Marine Information Center of the village

Reflecting: Identifying Enabling Factors for Community-Based Coral Health Monitoring and Early Warning System

Based on the results of participant observation and workshop, the elements enabling community-led coral health monitoring and early warning system in the study site are:

a. Training and team's capacity

Conducting various training sessions was essential to build the local community's proficiency in collecting monitoring and early warning system parameters. The primary training centered on certified diver training, a critical skill given that many monitoring methods require diving expertise. The diving training was facilitated smoothly for the local community due to their familiarity with diving using a compressor. The focus of the training was on proper utilization of SCUBA diving gear to ensure the community avoids using a compressor, which is deemed hazardous to their health. Other training then followed, including training on how to use various data collection equipment, data analysis, and data presentation.

b. Connection with government

Connection with the village government and the District Marine and Fisheries Agency was essential in formally establishing the community group responsible for monitoring and EWS. Institutionalized local group has provided a group identity for the local youth and allowed them to voice their concerns and undertake actions as a group (Hidayati et al., 2022).

c. Operation and maintenance of equipment

The digitalize of equipment has facilitated easy operation and maintenance, which is essential for community-led monitoring and Early Warning Systems (EWS).

d. Equipment availability and accessibility

Access to equipment is fundamental for collecting data for monitoring and Early Warning Systems (EWS). Equipment accessibility is facilitated through government support, university collaboration, and provision by NGOs.

e. Team's motivation

The main motivation of the Kabete Bajo Group is to restore the fish population. This objective is effectively articulated in the statements provided by group members, as follows:

"We wish to restore and preserve coral ecosystems to maintain the sustainability of marine life and ensure the health of coral reefs and their ecological services."

Female, 32 years old, village office staff

"As a fisherman, the most crucial thing is to restore fish populations through some form of restoration. Restoration efforts can help improve the fish population in the surrounding area. As we know, fishermen in our community now have to go far out to sea because many coral reefs are damaged, leading to the disappearance of fish. In coral reef restoration, it is mandatory to conduct monitoring to assess the progress of the restored coral reefs and to evaluate the effectiveness of the methods used."

Male, 27 years old, fisher.

f. Operational funds for monitoring

Numerous studies have underscored the importance of regular monitoring (Obura et al., 2019; Razak et al., 2022; Selkoe et al., 2015;). However, monitoring is frequently not implemented due to budget constraints, with operational funds posing a significant challenge, especially for community-led initiatives. This Participatory Action Research provides operational funds for the community for one year, enabling monthly monitoring activities.

g. Supporting regulations/policies

A review on policy related to coral restoration in Indonesia shows that All of Indonesia's regulations pertaining to coral reef restoration advocate for broad community participation, with ownership and responsibility shared between the government (both central and local) and local communities residing near and benefiting from reefs (Razak et al., 2022). For example, the emphasis on community-driven management of restoration is reaffirmed in Presidential Regulation No. 121/2012 ('Rehabilitation can be conducted through cooperation between government, regional government, individuals, or the community' [Article 12.1]).

h. Facilitation by Non – Government Organization

The facilitation carried out by the NGO includes the provision of equipment, training, and operational funds for monitoring and the early warning system.

i. Connection with university
Leveraging their expertise, the local university played a crucial role in enhancing the local communities' capacity to spearhead monitoring and Early Warning Systems (EWS) particularly on parameters that require further analysis including plankton, fish and invertebrates.

After identifying the enabler set, a structural self-interaction matrix (SSIM) was developed based on pairwise comparison of variables. The pairwise comparison was done during the workshop with the local stakeholders. The results are presented in Table 7.

Table 7. Structural Self-Interaction Matrix (SSIM)

ENABLERS	Enablers Description	i	h	g	f	e	d	c	b	a
a	Training and team's capacity	A	X	A	A	X	A	V	O	
b	Connection with government	O	X	V	O	X	V	O		
c	Operation and maintenance of equipment	A	A	O	A	A	A			
d	Equipment availability	A	A	A	A	X				
e	Team's motivation	X	X	X	X					
f	Operational funds for monitoring	O	A	O						
g	Supporting regulations/policies	X	X							
h	Facilitation by Non-Government Organization	V								
i	Connection with university									

Remarks:
V: enabler i (row) will help achieve enabler j (column);
A: enabler j will help achieve enabler i;
X: enablers i and j help each other;
O: enablers i and j are unrelated.

The SSIM was converted to Reachability Matrix. The results are presented in Table 8. The ISM model was crafted through an iterative process, revealing the interrelationships among the enabling factors (refer to Figure 4).

Table 8. Reachability Matrix

ENABLERS	Enablers Description	i	h	g	f	e	d	c	b	a	Driving Power
a	Training and team's capacity	0	1	0	0	1	0	1	0	1	4
b	Connection with government	0	1	1	0	1	1	0	1	0	5
c	Operation and maintenance of equipment	0	0	0	0	0	0	1	0	0	1
d	Equipment availability	0	0	0	0	1	1	1	0	1	4
e	Team's motivation	1	1	1	1	1	1	1	1	1	9
f	Operational funds	0	0	0	1	1	1	1	0	1	5
g	Supporting regulations	1	1	1	0	1	1	0	0	1	6
h	Connection with NGO	1	1	1	1	1	1	1	1	1	9
i	Connection with University	1	0	1	0	1	1	1	0	1	6
	Dependence	4	4	5	3	8	7	7	3	7	

Remarks:

a. If the (i,j) entry in the SSIM is a V, the (i,j) entry in the reachability matrix becomes 1 and the (j,i) entry becomes 0.
b. If the (i,j) entry in the SSIM is an A, the (i,j) entry inthe reachability matrix becomes 0 and the (j,i) entry becomes 1.
c. If the (i,j) entry in the SSIM is an X, both the (i,j) entry and the (j,i) entry of the reachability matrix becomes 1.

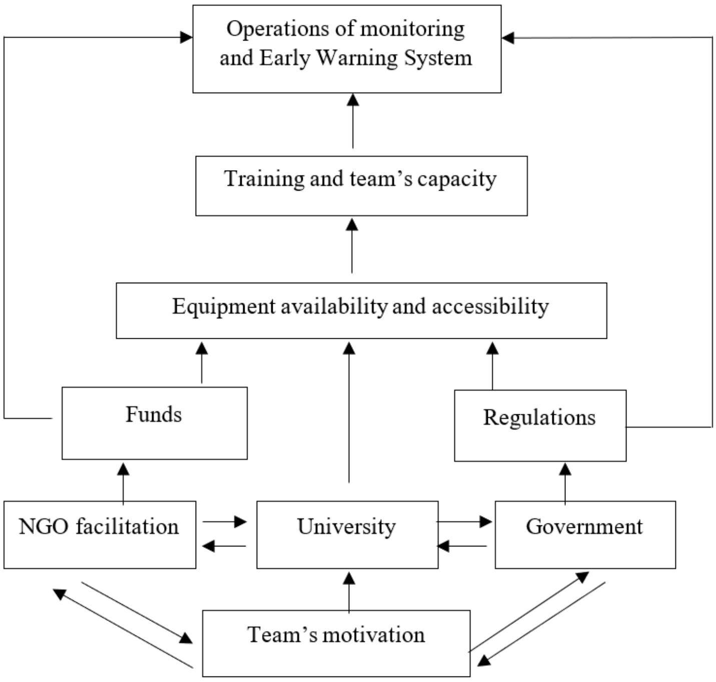

Figure 4. ISM of Enabling Factors for Community-led Coral Health Monitoring and EWS

Positioned at the base of the model is the "team's motivation" factor, signifying that for the other factors to function effectively, team motivation must be present initially. With its high driving power and dependency, this factor not only influences but is also influenced by the factors on the next level of the model (NGO facilitation, connection with the university, and connection with the government). The local community has ranked team motivation as the number one factor, indicating its utmost importance among all the factors.

Many studies have suggested that facilitations after institution is established are continuous to be critical (Ariyanto et al., 2020; Ichsan et al., 2019). Another factor with high drive power is NGO facilitation, primarily because the main source of funding to enable other enablers is derived from grants secured by the NGO.

MICMAC analysis facilitates identification of key factors driving the system based on drive power and dependence. The enablers are categorized into four clusters, namely, (I) autonomous, (II) dependent, (III) linkage, and (IV) independent (Figure 5).

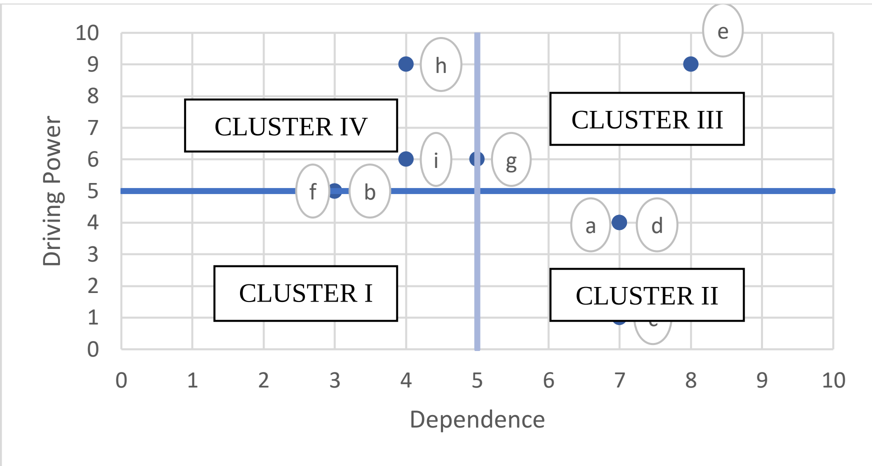

Figure 5. Driving power and dependence diagram

Cluster I – AUTONOMOUS:

The enablers in this cluster have weak drive power and weak dependence. They are relatively disconnected from the system, with which they have few links, which may be very strong (Attri et al., 2013). In this study, there is no enabler found in this cluster.

Cluster II – DEPENDENT:

The enablers in this category have a weak driving power, but strong dependence power (Talib & Faisal, 2016). In this study, three enablers (training and team capacity, operation and maintenance of equipment, and equipment availability and accessibility) are in this category. This implies that these factors cannot be realized without support from the Linkage and Independent factors.

Cluster III – LINKAGE:

The enablers in this cluster have strong driving powers as well as a strong dependence. They are also unstable, and so any action on them will have an effect on other and also a feedback effect on themselves. Team's motivation and supporting regulation are in this category. As a factor in the Linkage category, team's motivation is very crucial because they are the main actors who will lead the monitoring and EWS. At the same time, good team is also an important consideration for NGOs, universities, and the government when they decide which community to work with. In this research, supporting regulations are both influencing other factors and be influenced by other factors. A good community's profile will influence policy or regulations to support them particularly related to budget for operational budget in the future, for example, through the village fund (Hidayati et al., 2022)

Cluster IV – INDEPENDENT: Four factors are in this cluster, namely, connection with government, operational funds, facilitation from NGO, and connection with university. These enablers have strong drive power and weak dependence, meaning that they are essential forces to get the monitoring and early warning system running while at the same time are not being influenced by other factors in the model.

CONCLUSION

Monitoring and early warning system for coral reef health is feasible to be led by the local community. There are nine enabling factors identified and clustered into four clusters based on their driving power and dependency. Team's motivation and supporting regulation have strong driving power and dependency. Four factors (connection with government, operational funds, facilitation from NGO, and connection with university) have strong driving power and weak dependency. Three factors (training and team capacity, operation and maintenance of equipment, and equipment availability and accessibility) have weak driving power and strong dependence.

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