Integrated monitoring with SocMon/SEM-Pasifika: principles and process

An addendum to the Global Coral Reef Monitoring Network (GCRMN) Socio-economic Manual for Coral Reef Management

Supin Wongbusarakum and Adel Heenan

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Technical advice and guidance

The Global SocMon initiative (www.socmon.org) can provide technical advice, guidance and share experiences on the integration of SocMon/SEM-Pasifika with ecological monitoring. Contact Peter Edwards at peter.edwards@noaa.gov for further information.

Downloadable copies

Copies of *Integrated Monitoring with SocMon/SEM-Pasifika: Principles and Process* can be downloaded from the global SocMon website (www.socmon.org).

Comments and feedback

Comments on this addendum and feedback on how it was applied would be most appreciated. Please send to Maria Pena at maria.pena@cavehill.uwi.edu.

Author affiliation and contact information

Supin Wongbusarakum: Social Science Research Institute, University of Hawaiʻi at Mānoa, Honolulu, HI 96822, USA
supinw@gmail.com

Adel Heenan: School of Ocean Sciences, Bangor University, Anglesey LL59 5AB, UK
a.heenan@bangor.ac.uk

Disclaimer

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Purpose and target readers

The purpose of this addendum is to provide a systematic framework and a suggested process to integrate social with ecological monitoring. We hope that by taking this approach to integrate monitoring, more holistic information will be generated to inform coastal ecosystem management. This should in turn lead to plans and strategies that are developed to achieve desired biophysical and social outcomes for an Ecosystem based approach to natural resource management. This approach is intended to help strike the balance between ecological health with human well-being of coastal communities. We also hope that integrated monitoring will allow for a better understanding of the complex two-way relationships between people and coastal and marine resources and emphasize how important such an understanding is for policy decisions in coastal governance and sustainable development.

Integrated monitoring is a relatively new phenomenon under development but steadily gaining momentum globally. One of the major strategic objectives for the Global SocMon initiative (www.socmon.org) is to ensure that coastal ecosystem resource management decisions are informed through integrated social and biophysical monitoring. Effective coastal resource management is only possible if biophysical and social science disciplines work together at the inception of any monitoring program. The Caribbean and Pacific Islands SocMon have begun exploring the integration of SocMon/SEM-Pasifika with ecological monitoring and its application to decision-making. This work is only in its initial phase but is key to informing and solving management and policy needs particularly at the site and local levels.

The priority audience for this guide to integrated monitoring are practitioners of natural resource management and conservation. They may have different disciplinary training, including natural and social sciences, and are involved in coastal monitoring, management and sustainable development. We also target those who are interested in social-ecological systems and would like to apply an ecosystem approach to monitoring. The information in this chapter could also be applied in other sectors.

Background

Until recently monitoring objectives for natural resource management have primarily focused on biological and physical outcomes (Figure 1). Examples include collecting data to assess habitat condition, biodiversity, water quality, and species protection. Coral reef ecosystem monitoring from a biophysical perspective typically includes long-term tracking of, for example, fish biomass, coral cover, diversity of marine organisms, and physical conditions such as water quality, acidification, and water temperature. The development of the Global Coral Reef Monitoring Network (GCRMN) Socioeconomic Manual for Coral Reef Management (Bunce et al., 2000) and accompanying region-specific Socioeconomic Monitoring (SocMon) guidelines for the Caribbean, Central America, Brazil, South Asia, Southeast Asia, Western Indian Ocean, and Pacific Islands highlighted the importance of socioeconomic monitoring for coastal management planning and adaptive management of coral and other coastal and marine resources. The manual and regional guides offer practical tools and encourage participatory processes to monitor, among other things, coastal and marine activities, socioeconomic and demographic trends of the focal area management sites, perceived conditions of the resources, perceptions of management effectiveness, as well as perceived threats and solutions related to coastal resources and human communities.

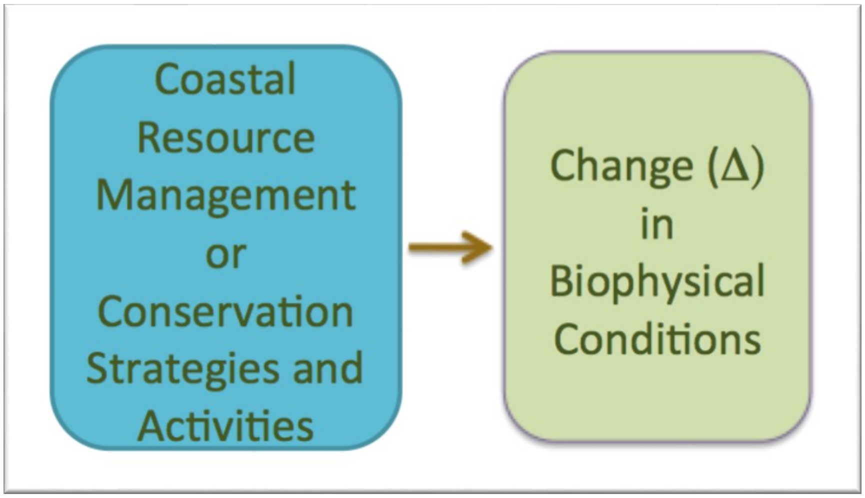

Figure 1: Conventional one-way relationship between coastal resource management and conservation with changes in biophysical conditions

While biological monitoring has a long history of institutionalization in many coral reef management and conservation initiatives, long-term socioeconomic monitoring has not been consistently established in many parts of the world. The majority of functioning socioeconomic monitoring efforts are limited to one-time assessments or based on very recent baseline assessments with limited ability to track trends over time (personal communications with SocMon/SEM-Pasifika regional coordinators and US National Coral Reef Monitoring Program Leads, May 2018). In many places, social data are limited to existing secondary data such as censuses that focus on community demographics (e.g. population size, density, employment profiles) and often do not match the scale or scope of either the management or conservation areas in question or the biophysical monitoring in these areas. As a result, there is a lack of adequate information about the interrelationship of social-ecological systems and complex two-way relationships between people and coastal and marine resources. Separate monitoring by social or natural scientists makes it difficult to detect the complex patterns, relationships and interacting processes of the two interconnected systems. Little seems to be understood about how changes in biophysical conditions impact ecosystem services, and what, if any, are the human well-being outcomes of management activities centered on ecological health.

With the launch of the Millennium Ecosystem Assessment (MEA, 2003), humans were acknowledged as an integral part of all ecosystems. Ecosystem services or the benefits people obtain from ecosystems were classed into four categories:

1. provisioning services such as food and water and nature-based materials and resources;
2. regulating services such as flood and disease control;

3. cultural services such as heritage, spiritual, recreational, and cultural benefits; and
4. supporting services, such as nutrient cycling, that maintain the conditions for life on Earth

(MEA, 2003)

At the same time, outcomes related to human well-being or people's ability to live a life they value (Wongbusarakum, Madeiraand Hartanto 2014), outcomes and importance of understanding them have received increasing attention in the fields of conservation and management of natural resources (Biedenweg, Stiles and Wellman 2016; Breslow et al. 2017; Coulthard et al. 2017; Wongbusarakum, Madeira and Hartanto 2014; Leisher et al. 2013; Smith et al. 2013; Dillard et al. 2013; Kittinger et al. 2012). Indeed, since the 1990s the number of studies on the relationship between nature and people and the impacts of resource management and conservation on both natural and social outcomes has grown substantially (McKinnon et al., 2016). While there are many frameworks that identify different human well-being domains, there are some that are the most commonly cited across different frameworks.

- Material living standards/economic wellbeing
- Health
- Education
- Security/safety
- Psychological/emotional/spiritual well-being
- Social relations
- Equity
- Culture

Like other types of environmental management, coastal management works best with integrative approaches to planning, implementing, and monitoring for evidence-based decision-making. A more comprehensive conceptual framework is needed to link social and biophysical sub-systems within the wider coastal ecosystem. In this way multidisciplinary monitoring data on the biophysical and socioeconomic aspects of the system can be brought together and used to inform the adaptive management of these important resources.

Moving towards integrated monitoring

Why integrated monitoring?

"Long-term and integrated monitoring through interdisciplinary research could provide reliable data to develop nexus between social, environmental and ecological data for use in influencing policy and informing timely decision making holistic management and development interventions"

(Chettri et al., 2015).

With the explicit recognition of human well-being within natural resource management policies and objectives, it becomes necessary to expand monitoring efforts to be relevant in an interdisciplinary context. The links between nature and people and how natural resource management and conservation affect changes in ecosystem services have received increasing attention from managers, researchers and conservation practitioners over the past decade. The traditional one-way relationship of resource management strategies that focus solely on the biophysical status of the ecosystem has been expanded towards an ecosystem approach to management, which includes ecosystem services as well as effects on human well-being (Wongbusarakum, Madeira and Hartanto, 2014) (Figure 2). Indeed, understanding social-ecological systems through integrated monitoring is becoming critical for successful management and conservation.

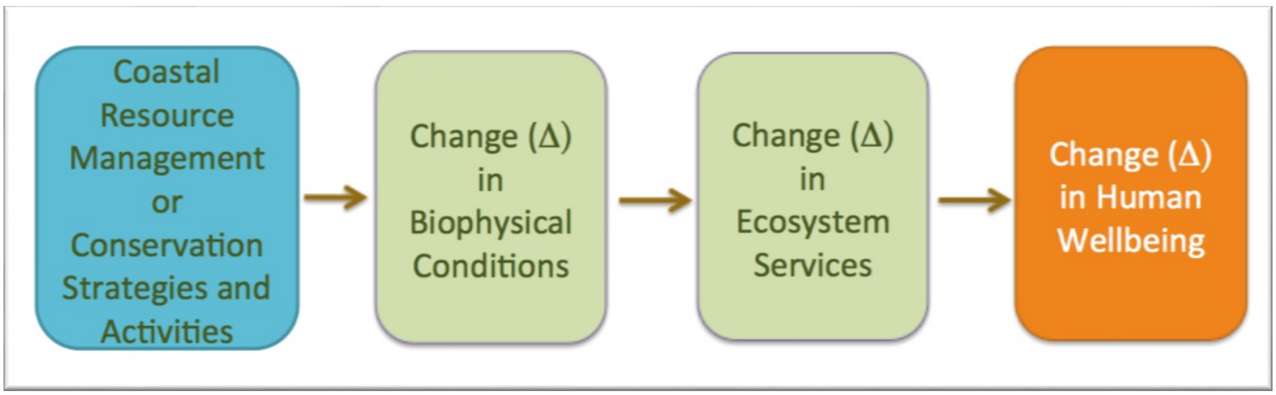

Figure 2: Adding ecosystem services and human well-being into management and conservation (Adapted from Wongbusarakum, Madeira and Hartanto, 2014)

Social-ecological systems integrate two complex sub-systems, the social (human) and ecological (biophysical) in a two-way feedback relationship (Berkes et al. 2016). Case studies of social ecological systems from around the world (Liu et al. 2007 in Berkes et al. 2016) show that these two subsystems can interact through non-linear dynamics, feedback loops and time lags. Many of these complex patterns and processes became apparent only when the full social-ecological system was taken as one unit of analysis. Coastal and marine management strategies can be either nature-oriented or socially-oriented but can affect changes in both biophysical and social conditions. Additionally, understanding interactions of biophysical and social systems is critical for planning and adaptive management decisions (Figure 3). The goal of integrated monitoring is to make explicit the linkages among social and biophysical systems and to monitor how changes in one affect the other. Achieving this goal requires the involvement of multiple disciplines in monitoring.

Integrated monitoring supports ecosystem-based management which is now widely acknowledged in global and national policies (e.g. CBD 1992; NOP 2012). There are a variety of global priority issues such as addressing the impacts of climate change and social adaptation, degraded natural resources and poverty, resource competition, food security and resource management. All of these issues require interdisciplinary research that can provide the depth and breadth of analysis needed to set the foundations for effective policy-making, planning, management, and public understanding.

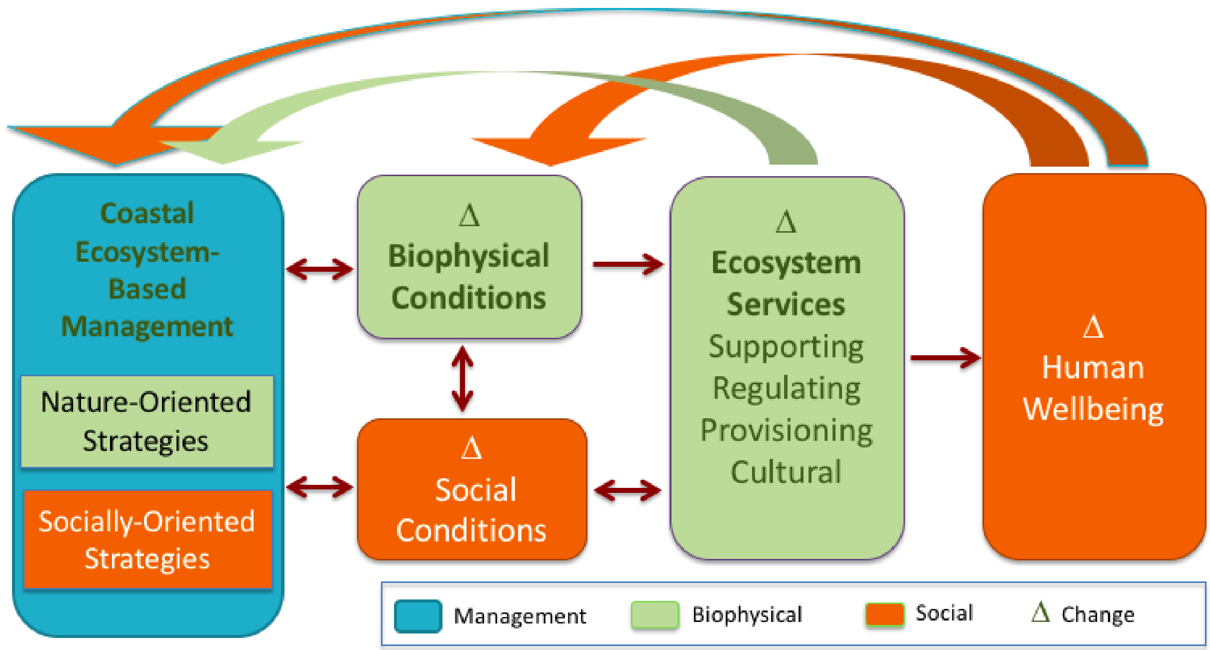

Figure 3: Interrelationships between ecosystem based management and social-ecological systems for a coastal system, adapted from Wongbusarakum, Madeira and Hartanto (2014).

Despite the obvious need for integrated monitoring approaches, comprehensive frameworks to guide how the typically separate biophysical monitoring and socioeconomic monitoring are brought together, are either lacking or limited in scope. Often, humans are considered and referred to in a negative context with regard to the environment. Terms such as human stressors, drivers, pressures or threats are commonly used in reference to the relationship between humans and natural resources. While it is necessary to monitor the *properties and functions* of an ecosystem (biophysical side), it is equally important to understand their *benefit to society* (socio-economic and cultural sides) (Boerema et al. 2017). Systematic reviews of peer-reviewed and grey literature (Boerema et al. 2017; McKinnon et al. 2016) show that, to date, benefits to people are most commonly measured for provisioning services because they are tangible and easy to quantify. Evidence of conservation-human well-being linkages have been mostly in the areas of economic or material well-being outcomes, and protected areas and governance outcomes. Large gaps of evidence for linkages exist in other important human well-being domains, such as health and education, and those that are intangible, including safety or security, culture or spirituality, psychological well-being, and social relations.

What is integrated monitoring?

Integrated monitoring can be defined as monitoring that brings together biophysical and socio-economic monitoring efforts to provide a greater understanding of the ecosystem, including human communities. Similar to interdisciplinary research, integrated monitoring is a process of answering a question or addressing a topic that is too complex to be dealt with adequately by a single discipline or profession (Klein and Newell 1997). An integrated monitoring approach will involve plans, designs, and objectives that include biological, physical, and socioeconomic data collection and analyses. These data can complement one another to produce a holistic view of the social-ecological system and its interactions, and to better understand how management might affect each of the individual sub-systems as well as their interactions. The monitoring is a collaboration of people with expertise from different disciplines employing different methods or tools. In practice, this would mean that SocMon and SEM-Pasifika efforts are to be integrated with the GCRMN biological and physical monitoring components leading to more holistic and multidisciplinary information, thereby allowing natural resource managers and decision-makers to better understand the linkages among the different sub-systems.

Levels of integration

The degree of integration in monitoring is likely to fall somewhere along a spectrum – with completely independent data streams at one extreme and fully integrated data streams at the other (Table 1). The points as which groups of people who are co-locating their bio-physical and socio-economic monitoring efforts will sit on this continuum will depend on several factors. These may include: the history of the individual monitoring data streams, the monitoring objectives, how long efforts towards integration have been underway, management needs to understand the links between social and biophysical changes, and opportunities for coordination and collaboration among the different disciplinary teams.

Table 1. The spectrum of interaction during various monitoring processes and how integrated ecosystem monitoring teams can operate together

Elements of monitoring system	Levels of Interaction		
	Low	Medium	High
	ISOLATIVE	COLLABORATIVE	INTEGRATIVE
Monitoring objectives	Are addressed via data from singular disciplines	Are addressed via data from multiple disciples	Are addressed via data from multiple disciplines and objectives are linked across disciplines
Indicators	Monitored independently	Monitored independently with an intent to integrate but the degree to which is variable	Monitored together, in a systematic and linked manner
Sampling design	Design is optimized for each discipline independently	Design informed through consultation and potentially involves compromise across disciplines	Design optimized to maximize multi-disciplinary (whole system) understanding at the cost of higher resolution single discipline data
Data collection methods	Mono-method and single disciplinary approach	Mixed-method and interdisciplinary approaches	Mixed-method and multidisciplinary approaches
Data analysis and reporting	Data analyzed and reported on separately	Data analyzed separately (or together) but interpreted/analyzed together	Data co-analyzed and reported to examine linkages across ecosystem indicators
Team interaction	Disciplinary experts work separately throughout entire monitoring cycle	Disciplinary experts work together under a shared monitoring goal, data sharing and interpretation can range from limited or frequent	Multi-disciplinary team members bring specific expertise, devise goals and objectives together, share leadership and decision-making authority and responsibility to report on data.

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Advantages and disadvantages of integrated monitoring

Hedge et al. (2013) identified two main advantages of integrated monitoring. Firstly, it can advance the understanding of cause-and-effect relationships (and interactions) within the bio-physical and social systems, and, if tied to an adaptive management framework, can improve the understanding of how management actions influence the ecosystem as a whole. The second benefit is that it can maximize use of resources made available for monitoring. It enforces clarity over the priority monitoring objectives, and explicitly links monitoring to management information needs. Thirdly, it allows the management to benefit from different types of data. For example, integrated monitoring provides quantitative information that can be used to compare changes over time or across sites, as well as qualitative data that provide more in-depth information regarding the situation, root causes and how people involved related the changes to their own lives. So, while integration can increase the cost of monitoring, it can lead to greater cost-effectiveness in the long run. Data collected by different monitoring programs will require review and assessment relative to the holistic social-ecological information needs for effective coastal management, rather than relative to the priority disciplinary needs that may have been identified without the wider-system level in mind.

In terms of disadvantages, since integrated monitoring requires multiple disciplines (as opposed to mono-method, singular discipline monitoring), it can be more resource intensive, more expensive (due to needs for more and varied information types), and more time consuming (especially with design and coordination among different teams). It also requires monitoring team members to learn about multiple methods, at least to the degree needed to understand the benefits of other methods and the gaps that they can help fill. Ideally there should also be a coordinator who can facilitate collaboration among the different team members, guide their development of shared assessment objectives that complement one another, and assist in synthesizing the different datasets in order to address those objectives. Integrated monitoring may come at the cost of higher resolution data in any one particular data stream. As an example see Heenan et al. (2016) for the information trade-offs experienced during the 15-year history of data collection for the National Oceanic and Atmospheric Administration (NOAA) Pacific Reef Assessment and Monitoring Program.

Given the advantages and disadvantages outlined above, it should not be assumed that integrative-mixed method monitoring is inherently better than mono-method monitoring (Molina-Azorin and Lopez-Gamero 2016) or should be a norm. A proactive, informed choice to conduct integrative monitoring and the extent to which data are integrated should be made, based on a process that transparently identifies and justifies the priority information needs for the social-ecological system, in relation to the management objectives and governing structures that are in place. An ideal point at which to decide upon the appropriate degree of integration is after a conceptual model of the system has been developed (see following example), and during the development of the monitoring objectives which is done with reference to the primary management information needs. Identifying the desired or feasible extent of integration at this point will also make decision-making about the optimal sampling design and methodology easier.

Process of integrating monitoring

This integrated monitoring guidance brief was developed for applications under the following assumptions:

1) The main monitoring actors, for example, the agency tasked with coastal management understands the need for, appreciates advantages of, and is willing to support integrated monitoring that will provide information on biophysical and socioeconomic aspects and the links management has with them. The management needs may be results of policy direction towards an ecosystem approach, interest in better addressing social-ecological linkages, or monitoring trends for interdisciplinary research;
2) There is a clearly defined boundary of an area for the multidisciplinary team to monitor;
3) The monitoring team members have expertise in different research fields, primarily social, natural and physical sciences, and they have the ability to influence and continue future integration of monitoring efforts and;
4) Monitoring is being conducted in an adaptive manner and is potentially tied to an adaptive management framework.

With these assumptions in mind, Figure 4 proposes a seven-step process through which integrated monitoring might be conducted. Each of these steps are discussed in the following sections. These steps share similarities with the assessment and monitoring stages identified in the GCRMN SocMon Manual (Bunce et al. 2000), while also taking the multiple objectives and the multiple disciplines into consideration.

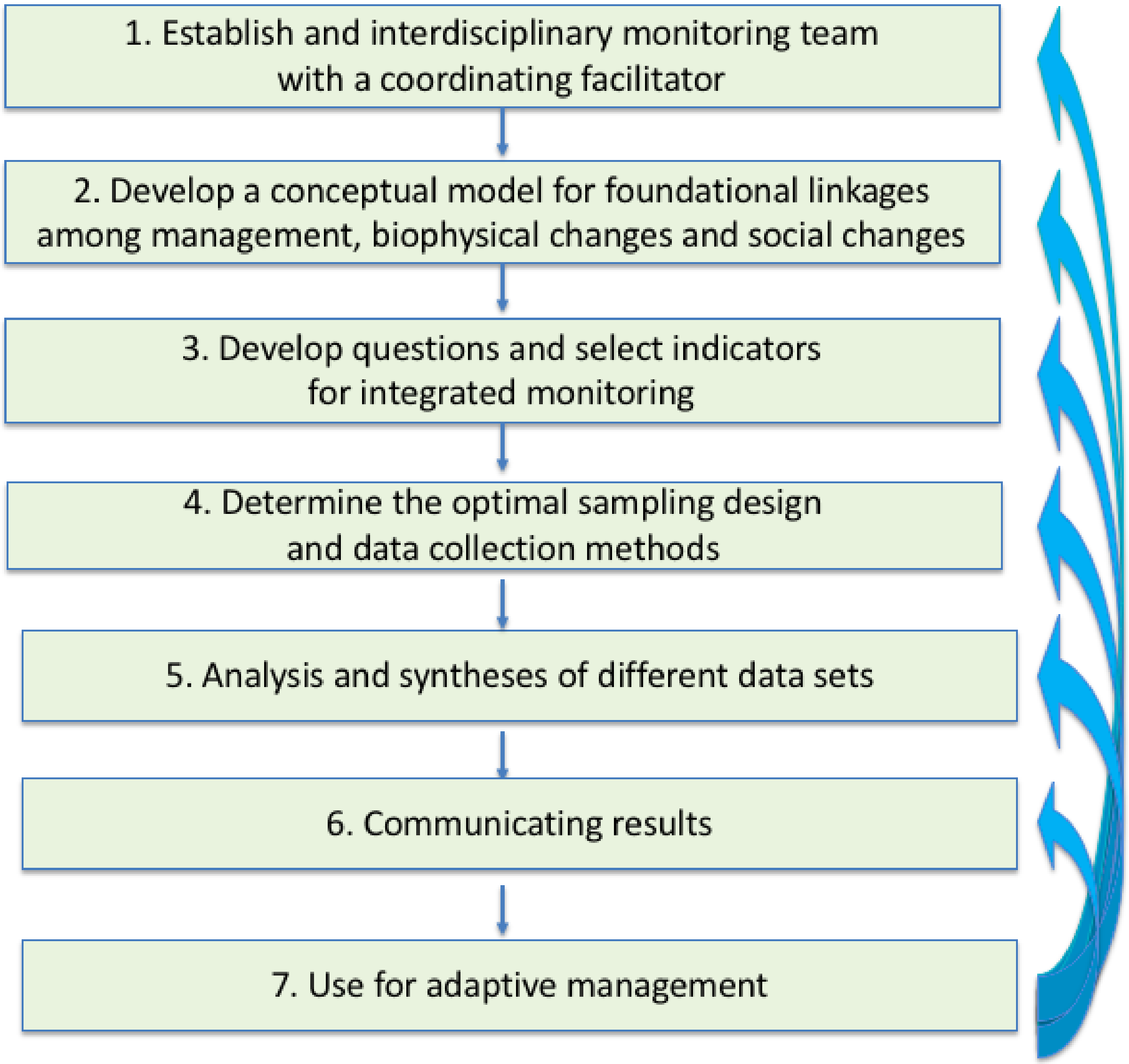

Figure 4: Process of integrated monitoring

1. Establish an interdisciplinary monitoring team with a coordinating facilitator

It is important for team members to recognize from the start that integrated monitoring processes involve challenges that any one individual member, working from his/her own disciplinary perspective (socioeconomic, biological or physical sciences), would be ill-equipped to handle, but where other team members will have relevant experiences. The extra effort expended at this stage in maintaining a cohesive, interdisciplinary research team will be beneficial in the long term. Adequate time must be allocated from the start to make sure ample opportunities exist for team members to communicate, develop active trust among one another, exchange ideas, share decision-making, and collaborate. Ground rules should be developed by the team members, and collectively agreed upon to make sure that team interactions are conducive to positive communication and collaboration. Funding agencies as well as organizations tasked with implementing an integrated monitoring effort need to recognize the need for interdisciplinary researchers to have time to learn the basics of each other's specializations. This groundwork is best done before tackling any major research issues and can involve clarifying technical language and views on the system in question.

Effective integrated monitoring is an interdisciplinary process that requires a cohesive and interdisciplinary research team with a strong collaborative work ethic and a commitment to learning about the system as a whole. Building the foundations for an effective team involves identifying a good mix of team members with expertise from socioeconomic monitoring and biophysical monitoring. These members should share motivations and values, and understand that integrated monitoring usually focuses on a real-world problem (Tait and Lyall 2007). The wider aim of the team is to generate a holistic understanding of, and strategic insights for, addressing complex interlinked issues so that the coastal management will be more effectively plan or adapt their strategies and actions.

Team members should be motivated by the interest to learn from other disciplines and must recognize that data from single-discipline research is not adequate for understanding research problems that generate information that will help inform effective policy-making. That is, the team members must share not only research objectives that address a problem but also interdisciplinary values. These values include:

- open-mindedness
- flexibility and adaptability
- a strong belief in the merits of collective understanding and in the validity of insights generated by different disciplines
- an appreciation of the advantages and disadvantages (as well as strengths and weaknesses) of multiple approaches and importance of their trade-offs
- tolerance for different methodologies or methods and points of views
- an ability to be constructive despite these differences
- a willingness to grapple with issue complexity and to investigate the connections between different sets of data and findings
- trust in the contributions made by team members from other disciplines, along with respect for their distinctive expertise.

Often people with different disciplinary backgrounds have different ways of understanding and communicating. Having a coordinator for the interdisciplinary monitoring team who can help facilitate communication and collaboration is crucial to the success of the team. The coordinator should have strong facilitation skills to support effective communication among different members, to synthesize the team interactions, and to ensure that the interdisciplinary process is well-designed and skillfully executed. Even when the monitoring is limited to a few disciplines and direct interactions are few, good coordination and regular collaboration during the research process are essential to project success.

The coordinator takes the role of bringing the research team members together and helps facilitate communications among the different disciplinary experts. The coordinator also ensures that each step of the monitoring design and implementation process is met and that synergies are optimized so that the team achieves the shared monitoring goals and objectives. It is the responsibility of the coordinator to help the team effectively address needs and issues that arise during the integrated monitoring process. Additionally, he/she helps negotiate or mediate when trade-offs or conflicts occur. He/she also helps determine whether specific issues can be better addressed by an individual monitoring team member or by the team as a whole. The interdisciplinary process employs both integrative and specialized approaches and recognizes the potential for contribution from each member at various stages of the research. Regular team meetings with the clear agenda of promoting cross-disciplinary dialogue and providing updates on the individual data streams serve both to reinforce interdisciplinary team cohesion and to remind team members of the shared goals of enriched learning opportunities, collective understanding, and better insights into an issue.

The coordinator should also take into consideration the contributions of local and traditional knowledge made by participating communities or other stakeholders and help facilitate (and schedule) accordingly. Assurances should be in place that stakeholder meetings are organized specifically for these purposes and that appropriate venues and communication methods are used. Sometimes, a group meeting with everyone may not yield equal input from different people and one-on-one discussions or other communication methods may need to be employed.

2. Develop a conceptual model for foundational linkages among management, biophysical conditions and social changes

A conceptual model should be developed with the goal of better understanding, amongst the entire team, the causal pathways and links between management and biophysical and social changes and desired results, and to provide a foundation for indicator development in the next step. The conceptual model can take the form of a diagram, theory of change, table, result chain or matrix. In an ideal situation, the people in charge of coastal management would work with teams who conduct the monitoring to develop the conceptual model, to ensure that the plausible causal pathways are understood and to select indicators that will help track the biophysical and social conditions aimed at by management.

Here we focus on one method of developing a conceptual model of the system - Theory of Change (ToC). A ToC includes feedback loops, can be used to illustrate a plausible cause-effect relationship among coastal management, and biophysical changes and social changes. A ToC usually includes basic components that link interventions with desired target changes, which could be near or middle-term outputs or long-term outcomes (Wongbusarakum, Madeira and Hartanto 2014; Collaborative Crop Research Program 2017). To the extent possible, assumptions made about causal relationships should be validated by experts and local stakeholders. The purpose of defining outcomes and developing ToCs is to validate the cause-effect relationship between a strategy and an outcome, and to guide implementation and monitoring and/or evaluation by prioritizing key questions for the integrated monitoring team. As such the ToC is best considered to be an iterative product. This is because ToCs, oncedrafted, are subject to the current conditions and assumptions on the system. Over time, these are likely to change and this requires a ToC to be revisited, recognizing that strategies, activities, and the indicators to monitor may each need to be adjusted.

Interdependency among changes in the environment and human well-being is complex, with pathways between biophysical and social conditions being interconnected, representing two-way relationships with feedback loops (Berkes et al. 2016). While some natural resource management or conservation strategies (e.g. protecting habitats and species through MPAs) focus on biophysical outcomes (improved habitat and species abundance), others can be socially-oriented (e.g. outreach and training to conserve reefs or alternative income generating jobs with less impacts on degraded fisheries resources to fishing households). Both strategies could be used to strengthen and inform one another, helping to ensure that neither has negative or unintended consequences for biophysical and social conditions, a situation that may happen when biophysical or social benefits are separately developed (Canavire-Bacarreza, Diaz-Gutierrez and Hanauer 2018). In conservation and natural resource management planning, we tend to expect the strategies to contribute to improving biophysical conditions, and in turn improving ecosystem services and human community well-being. Further, when conservation or management interventions result in improvements in people's lives, support for conservation can be enhanced (Wongbusarakum, Madeira and Hartanto 2014). Increased well-being could result in reduced pressure on natural resources and help affected communities perceive the importance of conservation strategies and positive changes in the biophysical environments for their own well-being. The ToC itself can be refined and revised over time.

In the examples below, we apply a ToC to a Marine Protected Area (MPA) strategy and illustrate how long-term management strategies and activities could be linked with desired biophysical changes, desired social changes, and outcomes. In this example management focuses on particular biophysical outcomes, especially improvement of reef conditions, along with other marine and coastal habitats, as well as increasing the abundance of marine species and biodiversity (Figure 5). These biophysical outcomes are linked in turn to expected social benefits and the provision of ecosystem services. Specifically, the availability of local nearshore sea foods, opportunities for the tourism sector, maintaining shoreline protection, and supporting cultural ecosystem services associated with healthy reefs, such as heritage, sense of place, and recreation. Management also has a socially-oriented strategy that focuses on developing locally appropriate sustainable alternative livelihoods that allow people to lessen their pressure on natural resources while also increasing or maintaining their income. This strategy is particularly important since access to parts of the areas where they used to fish or harvest marine life may be limited due to the MPA status. Examples of such livelihoods include job opportunities related to the MPA or conservation, ecotourism, or valued-added local products. For example, people catching sardines might sell them fresh at a low price, but if they produce fish sauce from the sardines, they can increase their profits. The strategy engages the local community in skill building and capacity development to be able to establish and sustain their alternative livelihoods. These biophysical and socially-oriented strategies are complementary and both strive towards an ecosystem status that can benefit both nature and people.

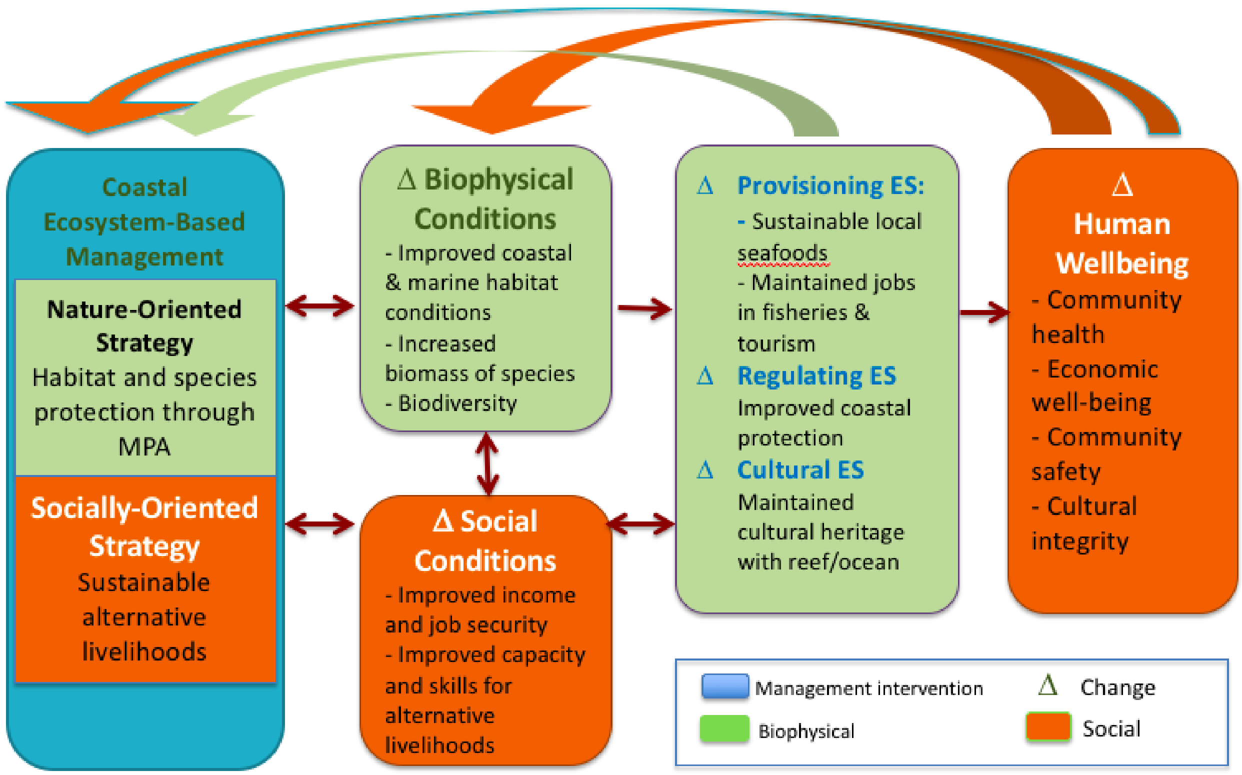

Figure 5: Example of coastal ecosystem based management theory of change with strategies related to MPA and sustainable livelihoods. The arrows illustrate the foundational linkages between management strategies and related changes in biophysical conditions and social conditions, which in turn impact ecosystem services and human well-being, and feedback loops.

The following actions should be taken into consideration when designing conceptual models for any integrated monitoring program:

1. Identify boundaries of the social and biophysical systems of interest, taking into consideration not only spatial areas, but also socioeconomic and political/administrative/management boundaries;
2. Identify key model components, subsystems, and interactions;
3. Identify natural and anthropogenic stressors that management wants to address;
4. Develop nature-oriented and socially oriented management strategies (concurrently) that address the identified stressors, making sure that desired outcome on both social and biophysical systems are considered;
5. Make plausible links among the management objectives addressing the stressors, desired changes in biophysical conditions and social conditions and results. The results maybe short or long term.

3. Develop questions and select indicators for integrated monitoring

With the conceptual model developed, it should be clear how management strategies may contribute to changes and outcomes in the biophysical conditions, ecosystems services, and social changes. The next step then is to identify clear and compelling research and management questions (Chettri et al. 2015) and a set of relevant measurable indicators of the desired output or outcome and processes (see Figure 6 for an example). Indicators are not arbitrarily chosen proxies of the different biophysical or socioeconomic aspects, but should serve to track the targeted changes and objectives (Addison et al. 2015), and should be carefully selected by disciplinary scientists as well as the local community and stakeholders. The process of developing questions and indicators should include review, feedback and adaptation of the design (Chettri et al. 2015). If possible, the indicators should also be tested "to ensure that they adequately reflect the reality of the measure they are approximating, that they are scientifically rigorous and practically applicable" (Boerema et al. 2017).

The underlying assumptions in designing integrative monitoring efforts are:

1) Management strategies and activities will impact the bio-physical condition of the system and/or be related to impacts on people in the system;
2) Bio-physical and social elements in the system, and variability in both will impact one another and these two-way interactions are taken into consideration;
3) A holistic understanding of these two-way interactionsor relationships are relevant to assessing management efficacy and for adaptive management.

Key integrated monitoring questions should be articulated and relevant indicators for the biophysical and socioeconomic monitoring can be developed. These indicators guide the type of data collected and in the later step - how the data should be analyzed and results communicated. Indicators are factors or variables that provide simple, precise, reliable and robust means to establish baselines and to measure change over time (Wongbusarakum, Madeira and Hartanto 2014). Some indicators are used to track changes related to intermediate results and outcomes, while others are process or implementation indicators used to monitor how management activities are implemented. Many of the existing indicators in the SocMon or SEM-Pasifika regional guidelines, especially those related to community demographics, coastal and marine resource uses, perception of resource conditions and resource governance, could be used as appropriate. Some additional indicators may need to be developed to better track ecosystem services of interest or human wellbeing outcomes that management strives for in the long run. Not all indicators monitored need to be communicated to information end-users and stakeholders, these can be monitored in the background. Which indicators are reported will depend on the key target audience (see communication strategy section).

Figure 6 below illustrates how biophysical and socioeconomic indicators can relate within an integrated monitoring framework. These are based on the previous example in Figure 5 with the management strategies on habitats and species protection through MPA and sustainable alternative livelihoods. The indicators in this integrated monitoring design address management implementation, the biophysical and social objectives of the management strategies, ecosystem services, and long-term human well-being outcomes. The indicators in the Figure are hypothetical and will need to be adjusted depending on the specific program, activities, objectives, local context, and resources.

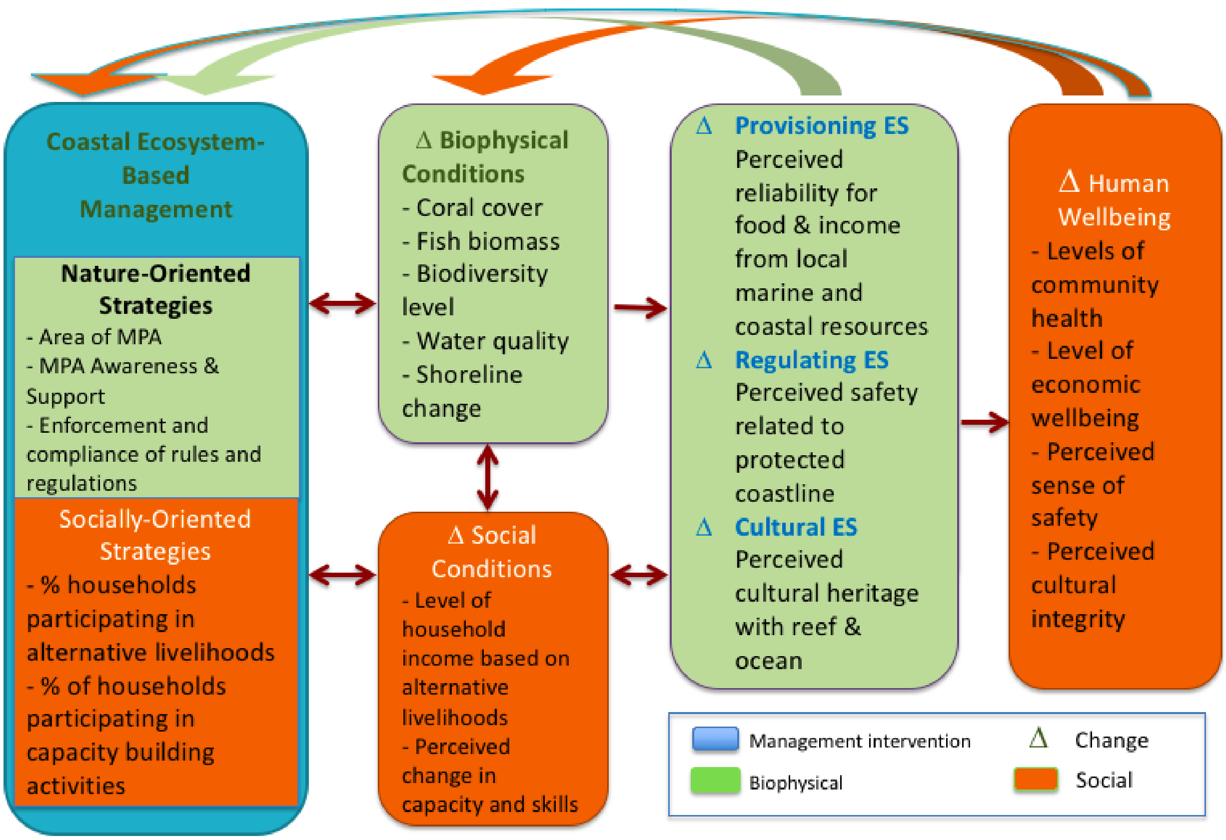

Figure 6:Indicators along the causal pathways of the theory of change applied to a MPA and sustainable livelihood strategies

Examples of socioeconomic indicator categories that can be potentially linked to observed biophysical changes in the coral reef ecosystem can be found in the GCRMN-Caribbean guidelines for integrated coral reef monitoring (GCRMN Caribbean UNEP, 2017 http://www.car-spaw-rac.org/IMG/pdf/gcrmn_carib_social_science_guideline_cop.pdf). The categories in the guidelines can be considered key drivers of ecological changes, and potentially linked to major industries and sectors such as tourism, fisheries, large scale agriculture, point sources for pollution, and land use. In addition, the guidelines provide recommendations for analyzing management-related indicators that can impact coral reef health and fisheries. These categories should be used at the conceptual model stage to frame the discussion and inform inputs into the model. These sectors can also be helpful for identifying key stakeholders and vulnerable groups.

Implementation Indicators

In addition to the indicators for the results and the outputs or outcomes of management strategies and activities, indicators can be added that will help track the implementation of the activities or the process by the management or monitoring teams. The purpose of implementation indicators are to inform and track progress on the implementation of the integrated monitoring activities for management. Proxy indicators for the following areas may need to be developed to fit the local context so that they can be used to gauge the degree to which the process of implementing management and monitoring activities are in line with best practices and with the principles and values of the programs. Examples of the process or implementation indicators are (adapted from Wongbusarakum, Madeira and Hartanto 2014):

- Stakeholder involvement/participation/consent of the monitoring, e.g. the level of involvement of the local communities in different activities organized by the management or monitoring teams;
- Social and cultural appropriateness of program activities to the local context, e.g. does the monitoring team consult with the local stakeholders/communities and take local protocol in designing field data collection methods?;
- Social safeguard and research ethics to protect the human subjects, e.g. are there data management and data sharing protocols in place? Is the free, prior, inform consent conducted?;
- Equity, e.g. levels of different ethnic or other demographic groups being included representatively in the sampling design;
- Accountability, e.g. is there a communication plan to report back the results of the analysis to the stakeholders and whether the reporting activity happens?;
- Effectiveness, e.g. are specific sampling objectives formalized? Is there a standard operating procedure in place for each data type collected;
- Transparency, e.g. are there established pipelines for the routine reliable and transparent reporting of data?

4. Sampling design and data collection

At this point, the team tasked with planning the integrative monitoring effort should have collectively developed: 1) a shared understanding of the integrated system from the conceptual model development process and; 2) have a list of priority indicators that directly linked the management strategy to management activities, biophysical impacts and outcomes along with social impacts and outcomes.

Equipped with these indicators to measure, the monitoring team will have to decide upon the sampling design for the program. This is a critical step as it will determine where, how, with what or whom, and the frequency of data collection on the individual indicators. For integrated monitoring in which there are different types of biological, physical and socioeconomic data-sets, it is important to make sure that the geographical scopes of each of the data collection efforts and the temporal scopes make sense. For example, the biophysical team may want to draw their samples from the managed or restored reef areas, while the socioeconomic team may want to consider their sample the population of people who use the coral reef ecosystem. This population could be the residential community adjacent to the reef areas as well as non-residential or local users, such as migrant fishers or tourists who are not permanently in the area. The GCRMN Caribbean framework described above also provides suggested frequency of sampling for various social and economic variables, many of which could be linked to ecological conditions (GCRMN Caribbean UNEP, 2017).

The integrated monitoring team should follow ethical principles of studies with human subjects outlined in the Belmont report (United States National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1978). The principles include: respect for the people, beneficence, and justice (See details at https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/index.html). When the integrated monitoring involves research[1] with human subjects, in many countries the team is required to apply for approval from an Institutional Review Board (IRB) from an affiliated research institution. An IRB is "an administrative body established to protect the rights and welfare of human research subjects recruited to participate in research activities conducted under the auspices of the institution with which it is affiliated" (Oregon State University Research Office, retrieved August 4, 2018). Prior to the data collection, the human participants are informed about the purpose and the process of the monitoring. Data can only be collected after they give consent to their strictly voluntary participation. At the same time, the monitoring team needs to develop data collecting and data analysis protocols to help protect the rights and the welfare of the participants. Collected data needs to be safely secured, stored and managed with full consideration for the confidentiality of the data, especially those related to personal identifiable information.

When different sets of data and different indicators are collected, it is important to take into consideration the timing of data collection—that is, when measurement of what can be done effectively. Changes in biophysical conditions, ecosystem services and human well-being often do not happen simultaneously and it is important to understand when the effects of each are measurable. A strategy for community engagement to create understanding of herbivorous fish on the coral health may work in relatively shorter period of time, when compared to changes in behaviour related to herbivorous fishing or changes in the increase of herbivorous fish that help remove algae and improve the condition of degraded reefs. Improved reef habitat and ecosystem services, such as increases in resources for fisheries and tourism, may take a while to change, and even longer periods may be needed to determine outcomes on community well-being for long term goals like economic security.

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[1] Research is defined as "a **systematic investigation**, including research development, testing, and evaluation, designed to develop or contribute to **generalizable knowledge"** https://www.bu.edu/researchsupport/compliance/human-subjects/determining-if-irb-approval-is-needed/.

Once the sampling units are delineated, we strongly recommend that before selecting the most appropriate sampling design for the program, the integrated monitoring team should seek input from both subject matter, local experts and statisticians. Factors to consider in sampling design may include: 1) what level of statistical power is appropriate to provide data to inform the selected management strategies; 2) through which process sampling sites will be selected and whether data collection on disparate indicators can be co-located at the same sites; 3) when and with what frequency data collection of the different indicators should take place; and 4) the feasibilities of long-term socioeconomic and biophysical monitoring. The answers to these questions will likely be determined by both practical (logistical and resource) and scientific constraints. We envisage the final sampling design will be arrived at via a degree of compromise between precision in measuring individual disciplinary indicators and the ability for drawing inferences across causal pathways. The final decision on sampling design and the selected priority indicators could also be influenced by policy or regulatory requirements.

Data collection on each set of the indicators along the theories of change (e.g. completion of activities, results on biophysical and social systems, results on ecosystem services and human well-being outcome) can be measured by disciplinary experts (e.g. fish scientists on herbivore biomass, benthic scientist on benthic substrate cover, and social scientist on change of community awareness, reliance on reef resources, or perceived changes in their cultural heritage), and may proceed as per monitoring in a mono-method, non-integrated manner. However, in the subsequent steps of conducting data analyses and interpreting the results of the different datasets, an integrative manner of the monitoring will become more apparent.

5. Analysis and syntheses of different data sets

The analytical options for integrating information from different indicators range from the qualitative, semi-quantitative and quantitative. Whatever the approach, it will require integrating different data types. Here, we assume that each data stream has standard operating procedures that outline the details on collection and methodology and that appropriate data management infrastructure is in place. These are essential pre-requisites to getting reliable data, analysis ready. For the social data, the procedures also help protect the welfare of human participants. The conceptual model is revisited again at this phase when results of the different indicators are brought together for interpretation of how management strategies and activities contribute to the changes in the different systems, comparing and contrasting of the different sets of results and synthesizing the overall meaning of the integrated monitoring.

The majority of bio-physical scientists engaged with monitoring will likely have limited to no experience of integrating qualitative information relevant to categorical and nominal data, such as levels of perceived enjoyment of near-shore activities by stakeholders, or the perceived fish biomass by self-identified fishers. It could also be challenging for them to analyze and synthesize the large amounts of qualitative data that come from interviews and group discussions. These mixed quantitative and qualitative data analyses are much more common in the social science domain and the participation of social scientists familiar with using mixed-method results should be encouraged in order to provide contexts to the quantitative results.

Analytical options to integrate disparate data types could include regression models of multinomial ordered and unordered categorical variables, fuzzy logic methods through to simulation methods (i.e. management strategy evaluation techniques that simulate management options on a model of the system e.g. Weijerman et al. 2016). Many quantitative analyses of biophysical data can be complemented by the qualitative data. For example, analyses of qualitative data could help identify in-depth root causes of degraded marine habitats and augment understanding of the pure percentage numbers of change in conditions over time. In another example, selected parts of interview data could help describe and highlight the importance of the connections of people to the place that needs better protection or of the spiritual value of certain species for which the biophysical data show declines. Furthermore, data can also be brought together via integrative indices, that centre on the conceptual modelling stage. One example are the Coral Reef Report Cards generated for the NOAA National Coral Reef Monitoring Program (e.g. http://ian.umces.edu/blog/2015/09/22/developing-a-report-card-for-the-coral-reefs-of-american-samoa/). It is also important for biophysical scientists to be familiar with quantitative social science data as well, some of which may have direct linkages to biophysical information. For example, the quantity of fish landed (and sold) per unit of coral reef area could be linked to the observed in-water fish biomass.

6. Communicating results

Any reporting activities should carefully consider the target audience, main message(s), communication products (tools) and pathways. Reporting options include data summary briefs, trend analyses, score or index cards, annual data reports or periodic synthesis reports that summary longer-term trends. Scientific research articles are also a good way of getting integrative analyses through peer review and can help gain scientific credibility to the program, however, the majority of resource managers and stakeholders might prefer a more distilled executive summary of the findings. Here again the emphasis should be on the linkages between the coastal management and the changes in both biophysical and social changes and the contribution to changes in relevant ecosystem services and human well-being. Integrated monitoring results should also be more interesting for a wider groups of stakeholders, instead of limited to those who are interested only in physical change, biological change, or socioeconomic changes.

Effective reporting of monitoring results is an essential component of a monitoring program and might be best achieved via the development and implementation of a communication strategy. This communication strategy should outline products that will be developed and tailored for different target audiences, the pathways to communicate the message(s) and associated timelines for their regular, routine delivery.

7. Linking integrated monitoring to adaptive management

Results of integrated monitoring are expected to be used in helping management to better understand the issues they are addressing and the extent to which their plans, strategies, and activities (or the lack thereof) are working towards the biophysical and social objectives. The ways to achieve this understanding should be adapted based on the learning from the monitoring results of both the results and the process in each of the assessments. At the end of each assessment, the integrated monitoring team members should discuss not only how each of the result sets are contributing to a better understanding of the interlinking social-ecological systems, but also how the ecosystem based coastal management contributes to the changes in biophysical and social systems. The monitoring team should continually ask whether the key questions and indicators are still relevant and whether the data are still providing answers (Chettri et al., 2015).

In addition to using integrated monitoring for adaptive management, the monitoring approach itself should be adaptive. The team members should also exchange lessons learned during the process of the integrated monitoring. These insights should be used to revisit and adjust the different steps for the future monitoring. Areas of adjustment may include: composition of the integrated monitoring team, conceptual model and each of its elements, monitoring questions and indicators, sampling design, and ways the different datasets are to be collected, interpreted, or communicated. Adaptive monitoring can be made directly relevant and be responsive to management information needs if it becomes integrated with the management process. More specifically, if policy-makers, resource managers, researchers and stakeholders are involved early in the planning process, in particular during the development of a conceptual model of the system, then monitoring objectives that align research, management and policy interests are more likely to be achieved.

Summary

In sum, rigour in integrated monitoring that is based on interdisciplinary research is a function of knowing how, why, and what to integrate (Szostak 2007). Consequently, the first activity after establishing an interdisciplinary team with a coordinating facilitator is to develop a conceptual model that explicitly describes the logical linkages of the different components, including management strategies, desired biophysical and social outcomes, and relevant indicators for each component. The needs for different datasets are then mapped out from the beginning of the process and monitoring project boundaries are clear. It seems quite likely that after indicators have been selected and/or developed, the data collection and parts of the analysis may be performed by the subject matter experts separately.

The interdisciplinary process employs both integrative and specialized approaches and recognizes the potential for contribution from each varying member at different stages of monitoring. Regular team meetings with the clear agenda of promoting cross discipline dialogue and providing updates on the individual data streams serve both to reinforce the integrated monitoring team cohesion and as reminders of the shared goals of enriched learning opportunities, collective understanding, and better insights into an issue. Once the data are analyzed, the results of the different datasets are synthesized so that the social-ecological relationships can be better and more comprehensively understood, communicated and used for adaptive management. The integrated monitoring itself, including the conceptual model is adjusted based on the learning from each assessment.

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