Integrating social and bio-physical monitoring: an initial framework for the Manell-Geus NOAA Habitat Blueprint Focal Area

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The purpose of this guidance brief is to outline how ecosystem monitoring might be integrated across the typically separate disciplines of the biophysical (ecology and oceanography) and social sciences. Despite the need for ecosystem based management (EBM) being widely acknowledged in global and national policies (e.g. CBD 1992, NOP 2012), little guidance exists on how ecosystem monitoring may adapt to meet this demand for more holistic and multi-disciplinary information, and important linkages between ecosystem-based management and ecosystem-based monitoring have not yet been adequately made. This guidance brief will outline a framework on how integrated monitoring that takes into consideration biological, physical and socioeconomic sciences can be implemented. The brief will serve as a starting point for an integrated monitoring plan for the Manell-Geus site in subsequent activities funded by NOAA Coral Reef Conservation Program in FY 2016 and FY 2017.

1. What is integrated ecosystem monitoring?

In a general sense, integrated ecosystem monitoring is monitoring that brings together biophysical and socio-economic monitoring efforts to provide a greater, whole systems understanding of the ecosystem, including human communities. Further insight into what might constitute integrated monitoring can be gleaned from considering these additional definitions on interdisciplinary research:

"A process of answering a question, solving a problem, or addressing a topic that is too broad or complex to be dealt with adequately by a single discipline or profession . . . Interdisciplinary studies draws on disciplinary perspectives and integrates their insights through construction of a more comprehensive perspective.

Klein and Newell (1996)

"Interdisciplinary research is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice."

Committee on Facilitating Interdisciplinary Research (2004)

More specifically, here we refer to integrated ecosystem monitoring as the objective and systematic integration of interests, data and knowledge across the policy, management and science sectors to monitor and inform the adaptive management of natural resources (*sensu* Hedge et al. 2010). That said, we recognize that 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 at the other (Table 1). Where any one group of people, who are co-locating their bio-physical and socio-economic monitoring efforts, sits on this continuum will depend on the history of the individual monitoring data streams, the monitoring objectives, and how long efforts towards integration have been underway.

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.

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

2. What are the advantages and disadvantages of integrated monitoring?

Advantages

Hedge et al. (2010) identify two main advantages of integrated monitoring. Firstly, it can advance the understanding of cause-and-effect relationships within the bio-physical and social system, and if tied to an adaptive management framework, can improve the understanding of how management actions influence the ecosystem.

The second benefit is that it can maximize use of the resources made available for monitoring. It enforces clarity over the priority monitoring objectives, and explicitly links monitoring to management information needs. So while overall, integration can increase the cost of monitoring (see below), it can lead to greater cost-effectiveness in the long run. Data collected by different monitoring programs will require review and be assessed relative to the priority ecosystem information needs, as opposed to the priority disciplinary needs that may have been identified without the wider-system level view of the ecosystem in mind.

Disadvantages

Mixed-methods and multi-disciplinary monitoring (as opposed to mono-method, singular discipline monitoring) can 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 Pacific Reef Assessment and Monitoring Program). More specifically, integrative monitoring will likely be more resource intensive, more expensive (more and varied information types are required), more time consuming and will require that monitoring team staff learn about multiple methods.

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 2014). 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 ecosystem, in relation to the management objectives and governing structures that are in place. An ideal point at which to decide upon the degree of integration is after a conceptual model of the system has been developed, and during the development of the monitoring objectives which is done with reference to the primary management information needs. Identifying the desired extent of integration at this point will make decision-making on the optimal sampling design and methodology easier.

3. How can integrated monitoring be linked to adaptive management?

This integration guidance brief is written with the following assumptions in mind: 1) there is a clearly defined monitoring boundary / area of interest; 2) there is / are team(s) tasked with the responsibility of bio-physical and socio-economic monitoring and they have the ability to influence future integration of monitoring efforts and; 3) monitoring is being conducted in an adaptive manner and is potentially tied to an adaptive management framework (Montambault et al 2015). Before we discuss how integrated monitoring might be facilitated, we will first briefly outline our working definition of adaptive monitoring and how this can be tied to adaptive management.

We adopt the Lindenmayer and Likens 2009 definition of adaptive monitoring, that is, monitoring composed of the following, iteratively linked steps: developing a conceptual model of the system, question setting, sampling design, data collection, data analysis and data interpretation (Figure 1). 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 managements, 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 and policy interests can be identified.

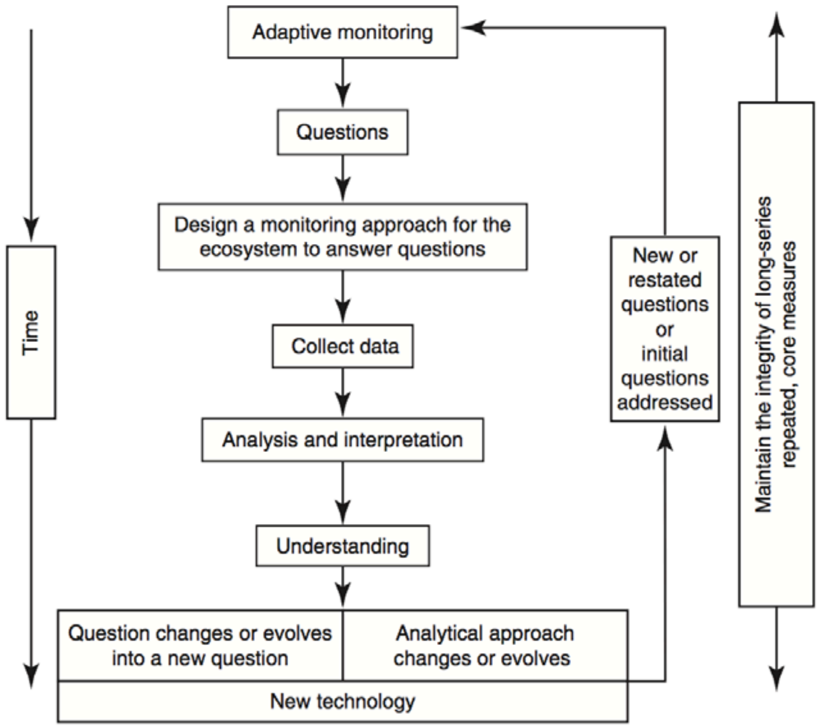

Figure 1. The adaptive monitoring cycle (Lindenmayer et al. 2011).

Here, we suggest a Theory of Change methodology to planning monitoring activities, to align adaptive monitoring to adaptive management in a manner that integrates bio-physical and social understanding of the system. The Theory of Change method first seeks to identify the long-term social, physical, biological, or ecological outcome or goal, and then with this framing in mind works backwards to identify management activities or interventions that could deliver on this desired outcome (Gerlet et al. 2011). Integration of the social with bio-physical sciences can be challenging, often because these specialisms require different methodologies, and specialists often have very different worldviews on the both the system and how to study it. Taking a Theory of Change approach can help to better understand the linkages between physical, biological and social change and impacts on the ecosystem, because it requires planners to consider the causal relationships between the bio-physical and social impacts and desired outcomes (Figure 2). With clarity in mind over the desired management outcome, and a whole systems view of how management interventions might influence the system via cross-disciplinary linkages, prioritizing the information needs and identifying indicators to be monitored should be reasonably straightforward.

In the following section, actions are discussed, which if included in the adaptive monitoring process could facilitate integrative monitoring. For the first step (developing monitoring objectives and indicators), these actions are illustrated using information from the Manell-Geus watershed in Guam.

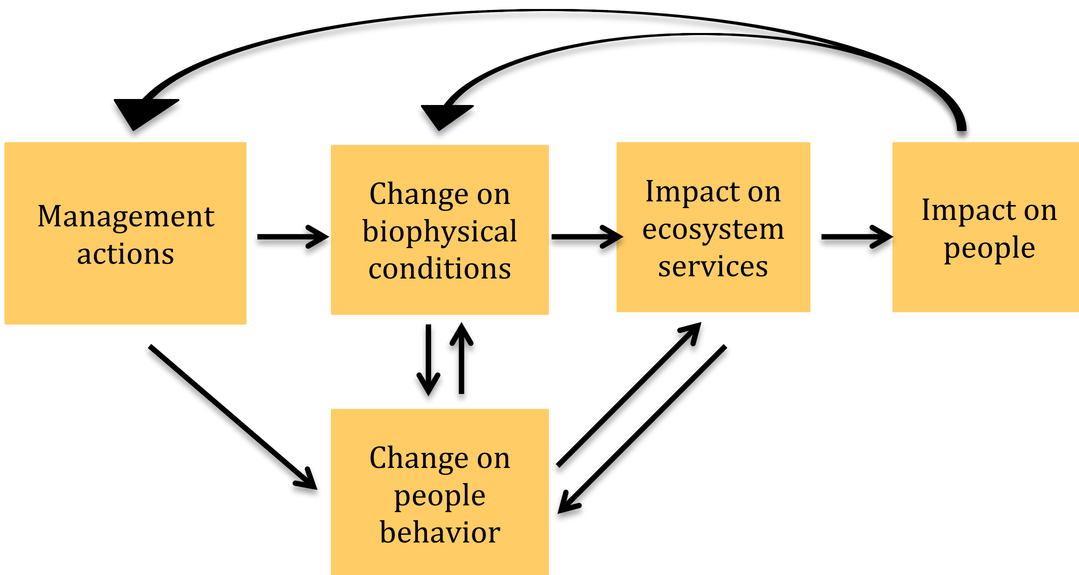

Figure 2. Theory of change methodologies make explicit the direct and indirect interactions between people's behavior, changes in bio-physical conditions, ecosystem services and people.

4. Actions to facilitate integration during monitoring

Monitoring objectives and indicators

As with most adaptive management frameworks, the brunt of the work lies in the planning stages. If planning is executed effectively, the doing (sampling design, data collection and analysis) should be relatively straightforward. Prior to setting the monitoring objectives and indicators, the integrated monitoring team should narrow down the scope of interest and ascertain the degree of integration deemed necessary to meet the information needs for management. A good activity to facilitate scope setting and a shared understanding of the integrated system is to develop a conceptual model of the system (i.e. an external representation). Ideally, the conceptual model will be jointly articulated by management, subject matter experts and stakeholders i.e. those with intimate knowledge of the system and the possible cause-effect relationships that characterize the area of interest. A good conceptual model will clearly illustrate the dynamic ecosystem processes and variables of the system, and assume human impacts and social outcomes are an implicit component.

Goss (2003) recommends the following steps to making a conceptual model during monitoring program development:

1. Clearly state the goals of the conceptual models
2. Identify bounds of the system of interest
3. Identify key model components, subsystems, and interactions
4. Develop control models of key systems and subsystems
5. Identify natural and anthropogenic stressors
6. Describe relationships of stressors, ecological factors, and responses
7. Articulate key questions or alternative approaches
8. Identify inclusive list of indicators

9. (Prioritize indicators)
10. Review, revise, refine models

The conceptual model can take the form of a diagram, cartoon, map, table or matrix, or a mathematical model. In the case of the Manell-Gues watershed, the conceptual model was developed using the Theory of Change methodology i.e. a table linking the long term management strategies to management activities and the interlinked bio-physical impacts and outcomes to the social impacts and outcomes (Table 2).

Strategy	**Activity**	**Intermediate result on biophysical change**	**Intermediate result on people**	**Biological outcome**	**Social outcome**
1. Engaging communities to protect reefs	Outreach on responsible fishing on herbivores	- Increased herbivores - Decreased algae	- Reduced herbivore fishing - Less herbivores to eat	Recovered coral reef ecosystem of increased resilience	Sustainable herbivore fishery
2. Engaging communities to control human induced fire	Fire outreach with community	Decrease fire and fire impacts	Less fire risks and damage	Recovered land and reefs	- Sustainable land use and food fish - Increased safety
3. Stream bank stabilization to reduce flood impacts	Riparian re-vegetation	- Decreased stream erosion - Decreased flooding impacts - Decreased amount of sedimentation near shore	- Less flood hazards - Increased opportunity to continue near shore activities that otherwise were compromised by impaired water	- Recovered reef - Good stream and near shore water quality	- Increased safety - Enjoyment of near shore activities

Table 2: Simplified theories of change for 3 strategies in Manell-Gues

Once management objectives, or social outcomes are clearly articulated via the Theory of Change framing, this can be used to identify indicators that will be measured and monitored along a causal pathway (plausible cause and effects relationships/models). In the Table 3 below, possible indicators (in yellow rows) for monitoring biophysical and social conditions are added to each of the causal pathways of the same examples from the previous tables.

Strategy	Activity	Intermediate result on biophysical change	Intermediate result on people	Biological outcomes	Social outcomes
1. Engaging communities to protect reefs	Outreach on responsible fishing on herbivores	- Increased herbivores - Decreased algae	- Reduced herbivore fishing - Less herbivores to eat	Recovered reef	Sustainable food fish
	- # of outreach - Quality of outreach (e.g. level of changed awareness and perception)	- Herbivore biomass - Amount of algae/area	-Number/ frequency of herbivore caught and consumed per household	- Coral and crustose coralline algal cover	- Amount of local fish consumption per household
2. Engaging communities to control human induced fire	Fire outreach with community	Decrease fire and fire impacts	Less fire risks and damage	Recovered land and reefs	- Sustainable land use and food fish - Increased safety
	- # of outreach - Quality of outreach (e.g. change on awareness and perception)	- Number of fires - Types and extent of impacts biophysical conditions - Level of sedimentation	- Number of household being impacted by fire - Types and extent of impacts on community and household levels (e.g. health, public and private property damage)	- Forest/ vegetated land cover - Coral cover	- Amount of local fish consumption per household - Perceived level of safety
3. Stream bank stabilization to reduce flood impacts	Riparian re-vegetation	- Decreased stream erosion - Decreased flooding impacts - Decreased amount of sedimentation near shore	- Less flood hazards - Increased opportunity to continue near shore activities that otherwise were compromised by impaired water	- Recovered reef - Good stream and near shore water quality	- Increased safety - Enjoyment of near shore activities
	Riparian	-	% of flood	Coral	- Perceived

	areas replanted	Sedimentation level in water - Land lose/damage due to flooding - Public and private property damage by flood	hazard reduction in the community - % of people conducting different near shore activities	cover and water clarity	level of safety related to flood - Level of near shore enjoyment

Table 3: Indicators for each stage of the theory of change on the Manell-Geus strategies

The underlying assumption of designing integrative monitoring efforts via consultation of scientists from different disciplines using the theory of change to identify indicators along these causal pathways are that:

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-physcial 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 interactions / relationships are relevant to assessing management efficacy and for adaptive management.

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 making and; 2) have a list of priority indicators that directly linked the management strategy to management activities, biophysical impacts, and biological outcomes along with intermediary human impacts and social 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 and with what frequency data on the individual indicators will be collected. We strongly recommend that the integrated monitoring team seek input from: 1) subject matter experts and; 2) statisticians before selecting the most appropriate sampling design for the program. Factors to consider in sampling design include: 1) what level of statistical power is appropriate to provide data to inform the selected management strategies; 2) through which process will sampling sites be selected and can data collection on disparate indicators be co-located at the same sites and; 3) with what frequency should data collection take place. The answer to these three questions will likely be determined by both practical (logistical and resource) and scientific constraints. We envisage the final sampling design will be arrived upon via a degree of compromise, in terms of precision to measure one disciplinary indicator perfectly and the ability for inference across the causal pathway.

Data collection on each set of the indicators along the theories of change (i.e. activity, intermediate result on biophysical, intermediate results on people, biological outcome, and social outcome) can be measured by disciplinary experts (e.g. fish scientist on herbivore biomass, benthic scientist on benthic substrate cover, and social scientist on change of community awareness and perception or amount of fish consumption by household). In this regard, data collection may proceed as per monitoring in a mono-method, non-integrated manner. This is particularly true for the bio-physical and social indicators. Data analyses and interpretation will likely be the next step where the fact that monitoring is happening in an integrative manner becomes apparent.

Data analysis and reporting

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.

The majority of bio-physical scientists engaged with monitoring will likely have limited to no experience of integrating quantitative and qualitative information, such as the perceived enjoyment of near-shore activities by stakeholders and indicators on near-shore water quality, or the self identify as fishers and indicators on fish biomass. These types of mixed data analyses are much more common in the social science domain. Analytical options to integrate disparate data types 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).

Any reporting activities should carefully consider the target audience. 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.

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 and associated timelines for their regular, routine delivery.

Teamwork

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 multiple disciplines, who share motivations and values, and who understand that integrated monitoring usually focuses on a real-world problem (Tait and Lyall 2007), and aims at generating a holistic understanding of and strategic insights for addressing complex interlinked issues.

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/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.

It is important for team members to recognize from the start that integrated monitoring involves challenges for which any one individual member, working from his/her own disciplinary perspective, would be ill equipped to handle, but in relation to which other team members will have relevant experience. Extra effort is thus needed to promote a cohesive, interdisciplinary monitoring team, and the start-up phase of the monitoring will take longer. Adequate time must be planned for from the start to make sure ample opportunity is provided for team members to communicate, gain trust among one another, exchange ideas, share decision making, and collaborate. A team coordinator is helpful to facilitate effective communication among different members. 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.

In sum, rigor in interdisciplinary research is a function of knowing how, why, and what to integrate (Szostak 2007). Consequently, the first activity of the team is to develop a conceptual model that explicitly describes the logical linkages of the components of the research and relevant indicators for each component. The needs for different data sets are then mapped out from the beginning of the process and research project boundaries are clear. It seems quite likely that after indicators have been selected, 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.

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