Ecological Indicators 44 (2014) 11–25

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Using the integrated ecosystem assessment framework to build consensus and transfer information to managers

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ARTICLE INFO

Article history:
Received 29 August 2013
Received in revised form 17 March 2014
Accepted 24 March 2014

Keywords:
Ecosystem-based management
Integrated ecosystem assessments
South Florida
EBM-DPSER
Conceptual ecological models
Bayesian Belief Networks

ABSTRACT

Ecosystem-based management is widely regarded as a method to improve the way we manage our coastal marine resources and ecosystems. Effective ecosystem-based management relies upon synthesizing our scientific knowledge and transferring this knowledge into management actions. Integrated ecosystem assessment is a framework to conduct this scientific synthesis and transfer information to resource managers. Portions of the framework were applied to build consensus on the focal ecosystem components and processes that are characteristic of a sustainable South Florida coastal ecosystem that is producing ecosystem services at the level society desires. Consensus was developed through facilitated meetings that aimed to conceptualize the ecosystem, develop ecosystem indicators, and conduct risk analysis. Resource managers, researchers, academics, and non-governmental organizations participated in these meetings and contributed to the synthesis of science and a myriad of science communications to transfer information to decision makers and the public. A proof of concept Bayesian Belief Network was developed to explore integrating the results of this assessment into an interactive management scenario evaluation tool. The four year effort resulted in the development of a research and management coordination network in South Florida that should provide the foundation for implementing ecosystem-based resource management across multiple agencies.

1. Introduction

Ecosystem-based management (EBM) can be defined simplistically as an operational strategy to manage the ecosystem in a holistic manner and is widely accepted as a method to improve natural resource management (McLeod et al., 2005; Szaro et al., 1998; Christensen et al., 1996). A primary goal of EBM is to achieve a balance between the needs of society, the environment, and institutional arrangements (Slocombe, 1993). To achieve such a balance requires knowledge regarding the complexities and intersection of biophysical science, human dimensions, and governance mechanisms (Altman et al., 2011; Kelble et al., 2013; Rosenberg and McLeod, 2005; Slocombe, 1993; Szaro et al., 1998).

Implementing EBM poses numerous challenges to decision makers. Many of these challenges are tied to understanding the interconnectedness of the dynamic environment and the coupled socio-ecological system, often when scientific information and management processes do not efficiently serve one another. These challenges become pressing concerns to address in a timely manner as coastal populations grow and declines in the health of marine and coastal ecosystems continue (Keller et al., 2009; Leslie and McLeod, 2007; MEA, 2005; POC, 2003; USCOP, 2004; WHCEQ, 2010). The primary challenge facing managers is assimilating complex information, drawing substantive inferences from this information, and then translating these inferences into concrete and defendable management actions. Integrated Ecosystem Assessments (IEAs) are a process designed to overcome or, at least, minimize this challenge (Levin et al., 2009; Reiter et al., 2013).

IEAs provide ‘a formal synthesis and quantitative analysis of information on relevant natural and socioeconomic factors, in relation to specified ecosystem management objectives’ (Levin et al.,

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http://dx.doi.org/10.1016/j.ecolind.2014.03.024
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2009). The IEA approach includes scoping and stakeholder engagement to aid in defining ecosystem goals, targets, and indicators. Thus, the IEA process provides opportunities to bring together stakeholders for developing consensus designed to inform EBM implementation and decision-making (Tallis et al., 2010; deReynier et al., 2010; Levin et al., 2009, 2013). Because the role of these interactions in the IEA framework is not explicit, a modification of the IEA process has been proposed to increase the interactions with management and provide tangible products to support management decision-making (Reiter et al., 2013).

IEA and other scientific processes designed to inform EBM should in their early stages address the need for building a science-based consensus of the current state of the ecosystem (Harwell et al., 1996). The consensus-building process is reliant on active, two-way stakeholder engagement. Scientists, resource managers, and stakeholders need to be engaged at the onset to present their scientific knowledge of the ecosystem and develop a consensus of not just how the ecosystem functions, but also how humans interact with the ecosystem. After developing the science-based consensus, management and stakeholder entities must be engaged to communicate this consensus in an effective manner to further their missions.

In South Florida, the MARine and Estuarine goal-setting project (MARES) sought "to reach a science-based consensus about the defining characteristics and fundamental regulating processes of a South Florida coastal marine ecosystem that is both sustainable and capable of providing the diverse ecosystem services upon which our society depends." This goal is directly aligned with the IEA process in that it seeks to develop scientific consensus through the development of EBM goals and indicators. Moreover, MARES and IEAs both have the specific aim of conducting this consensus building to increase the use of science in resource management decision-making. We will discuss how MARES applied the established IEA steps for defining EBM goals, developing indicators, conducting risk analysis, and evaluating scenarios and supplemented these with continuous and ongoing engagement with managers in an attempt to improve the transfer of scientific knowledge into resource management decision making in South Florida.

2. Methods

South Florida's coastal marine ecosystem is located at the southern tip of the Florida peninsula. The MARES domain spanned from the Caloosahatchee River Estuary on the west coast, through the

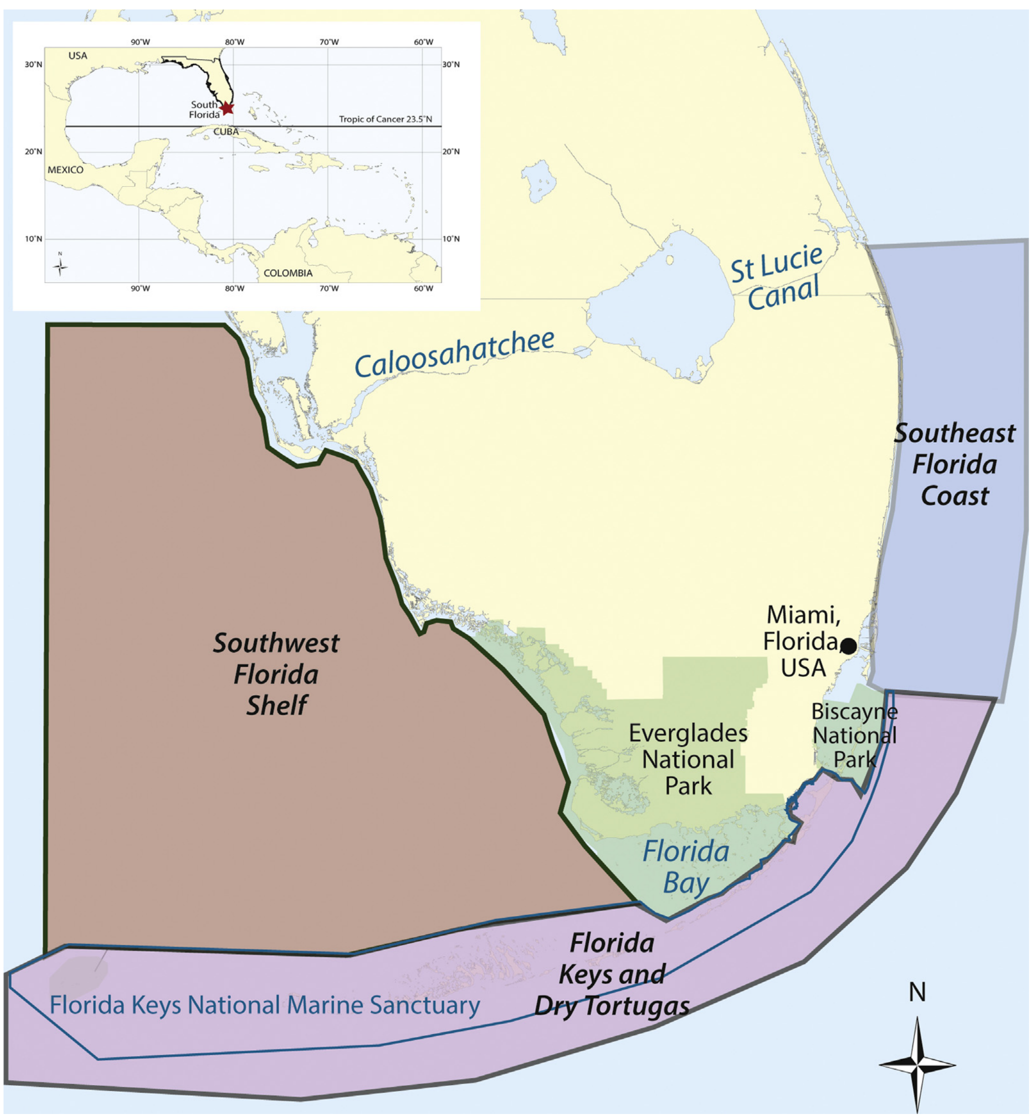

Fig. 1. The South Florida IEA is comprised of the Marine and Estuarine Goal Setting for South Florida (MARES) project domain. It encompasses the marine and coastal components of the southern tip of the Florida peninsula.

southernmost region of the Florida Keys and Dry Tortugas, and to the southeast coast northward to the St. Lucie River Estuary (Fig. 1). To better engage stakeholders and resource managers, we divided South Florida into three subregions: Southwest Florida Shelf, Florida Keys and Dry Tortugas, and Southeast Florida Coast.

MARES focused on four steps in the IEA process (1) scoping, (2) indicator development, and (3) risk analysis, and (4) evaluating scenarios. However, MARES had as its central hypothesis that developing consensus through integration between natural systems scientists, human dimensions scientists, resource managers, and non-governmental organizations (NGOs) would improve the use of science in resource management decision-making. As such, MARES had a leaders group with representatives from Everglades National Park, Florida Keys National Marine Sanctuary, University of Miami, Florida International University, the National Oceanic and Atmospheric Administration, Florida Department of Environmental Protection, Florida Fish and Wildlife Conservation Commission, and Audubon of Florida to ensure the methods being employed were appropriate for building consensus in a manner that would improve resource management. Moreover, significant focus was placed upon communications and engagement with stakeholders and resource managers to keep them involved in the process and promote the transfer of this scientific knowledge to management.

2.1. Scoping

The South Florida project employed consensus building throughout the scoping process. Ralph and Poole (2003) define consensus building as "an interpersonal and political process designed to facilitate decision-making in the divisive and contentious political environment that surrounds the development of natural resource management policies." The multidisciplinary nature of EBM underscored the importance of consensus building and illustrated the value of including it as an internal component when integrating natural and human dimensions science (Fox et al., 2006; Slocombe, 1993; Weichselgartner and Kasperson, 2010). The scoping process included several components intended to synthesize current knowledge and systems viewpoints. The process included information exchanges and briefings, conceptual diagram development, and integrated conceptual ecological model (ICEM) development. Throughout the project, multiple streams of communication were used to encourage information sharing to improve the synthesis of knowledge (Fig. 2). Exchanges occurred in person at workshops or through social media, E-mail, online meetings (GoToMeeting, 2013), or interpersonal communications.

The crux of the MARES scoping process was four two-day facilitated workshops, one in each sub-region and one for the total South Florida coastal marine ecosystem. All workshops were announced publicly via the project website, public listservs, and during public meetings related to resource management in the region (e.g., U.S. Coral Reef Task Force). Moreover, we specifically targeted NGOs to represent the viewpoints of their constituency. Each workshop was attended by 40–60 participants from federal, state, and local agencies, academic researchers, NGOs, and an elected official.

The facilitated workshops were used as a forum to present ideas and to build consensus regarding the structure and function of the coastal ecosystem, including humans. In most instances, consensus was achieved by general agreement. These workshops first aimed to develop a conceptual diagram that depicted the ecosystem, including relevant human activities. During regional workshops, participants were split into groups and asked to create a diagram of the ecosystem. Group discussion was used to create and refine these diagrams representing the biophysical and human dimensions of the ecosystem in a visual format for science communications with policy makers and non-technical audiences (Dennison et al., 2007; Likens, 2010). Sometimes, one or two participants led the effort, and in other instance several individuals joined in the exercise. The group reviewed their drawing and when consensus on the content of the sketches was achieved, a photograph was taken, and the drawings were recreated in Illustrator CS6 software (Adobe, 2012) and shared with participants for review (Fig. 3). Diagrams were added to subsequent reports, presentations, and fact pages to share a visual representation of the complexities of the ecosystem with non-technical audiences.

The conceptual diagrams were then used as the basis for developing ICEMs that described cause and effect relationships in the ecosystem, and identified focal ecosystem components for both biophysical and human dimensions. A modified Drivers-Pressures-States-Impacts-Responses (DPSIR) framework (OCED, 1993; UN, 1996) termed EBM-DPSER was used to develop the ICEMs. The primary modification in the EBM-DPSER framework was to emphasize the importance and explicit inclusion of ecosystem services by replacing the Impacts module in DPSIR with Ecosystem Services in EBM-DPSER (Kelble et al., 2013) (Fig. 4). Ecosystem services in the South Florida project were defined as the benefits that humans derive from the ecosystem (MEA, 2005). They linked people to the state of the ecosystem using the terminology "Ecosystem attributes that people care about" (Kelble et al., 2013). The attributes were carefully selected to capture services that had value for both people who live in the South Florida ecosystem and people who do not. The value of the ecosystem service was related to environmental conditions, and this value was measured and reported in a monetary, cultural, or social context (Loomis and Paterson, 2014).

The state module of EBM-DPSER ICEM was further described by developing state models for each of the focal ecosystem components in the state module. Prior to each regional workshop, a subset of project participants were asked to draft a conceptual ecological model (CEM) for states of the ecosystem (Gentile et al., 2001). These individuals were regarded as experts in their field of science. Draft models were presented for further comment during the regional workshops. Final drafts of the diagrams were put into a standardized format for reporting.

The CEMs were used to impart the knowledge about the ecosystem with the appropriate target audience with emphasis on the linkages among the components. CEMs provided a more technical

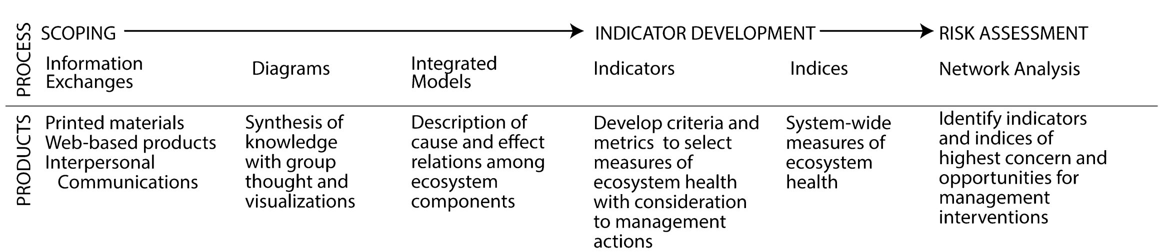

Fig. 2. South Florida IEA process and products. Project participants, staff and representatives from regional academic, government, and non-governmental offices, engaged in scoping, indicator development, and risk assessment activities. Throughout the process, multiple streams of communications were developed to transfer information to managers and stakeholders.

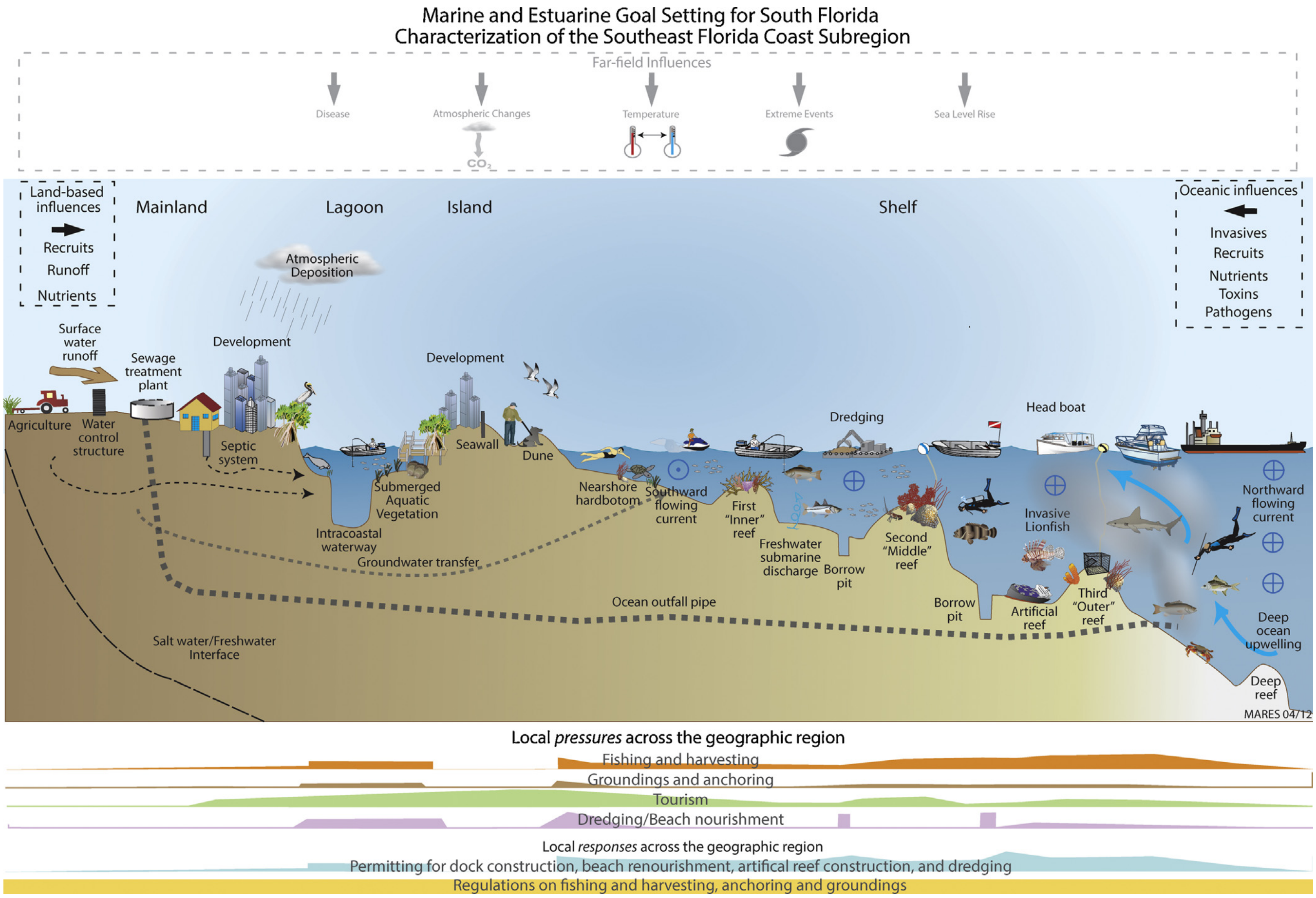

Fig. 3. During a scoping exercise, workshop participants sketched their view of the ecosystem, reviewed the drawings, and then staff recreated the sketch in Adobe Illustrator software for inclusion in reports and project communications.

view of the ecosystem than the conceptual diagrams and helped characterize and assess an ecosystem using a systematic approach to identify drivers, stressors, and desired endpoints with considerations of risk and uncertainty tied to alternative futures (Fig. 5). Gentile et al. (2001) and Reiter (2004) illustrated the utility of these models as management tools that aid in identifying societal preferences and ecological states and the linkages among these.

Work groups used the consensus built during the scoping process to create reports describing focal ecosystem components within the EBM-DPSER model allowing one report to reflect the consensus knowledge of all workshop participants. Work groups presented a synthesis of scientific knowledge on a particular component of the ecosystem followed by an open discussion of how to

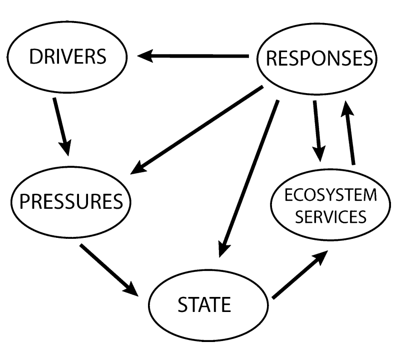

Fig. 4. ICEMs are based on the DPSER framework which describes the ecosystem in terms Drivers, Pressures, State, Ecosystem Services, and Response (Kelble et al., 2013).

move that science into the IEA framework. In some instances, workshop attendees ranked and prioritized features of the environment by placing adhesive dots on a poster listing each of those features, in other cases, they used audience response systems (Turning Technologies, 2013). These methods characterized areas of convergence and divergence within the expert knowledge base in the room. Divergent topics were discussed in a facilitated session to gain consensus from participants. Workshop reports were shared for review and additional comment as a final opportunity to illustrate acceptance of the synthesis and findings.

2.2. Indicators

Indicators are quantitative measures that assess the status of the ecosystem (Doren et al., 2009). They are most useful when assessing the status relative to a pre-defined goal. Because the stated goal of MARES was an ecosystem that is sustainable and capable of delivering societally desired levels of ecosystem services, selected indicators were required to be scientifically defensible and able to assess the ecosystem relative to this goal. To accomplish this objective a set of 11 criteria for ecosystem indicators were described based upon previously applied indicator criteria in the literature and input from workshop participants (Table 1). Indicators were developed based on these criteria for both the biophysical and human dimensions of the ecosystem. This led to a large number of indicators that reduced the ability to quickly communicate the status of the ecosystem. Thus, MARES aggregated indicators into indices providing a hierarchy of information relevant to a broad array of audiences. The hierarchy of indicators enabled a

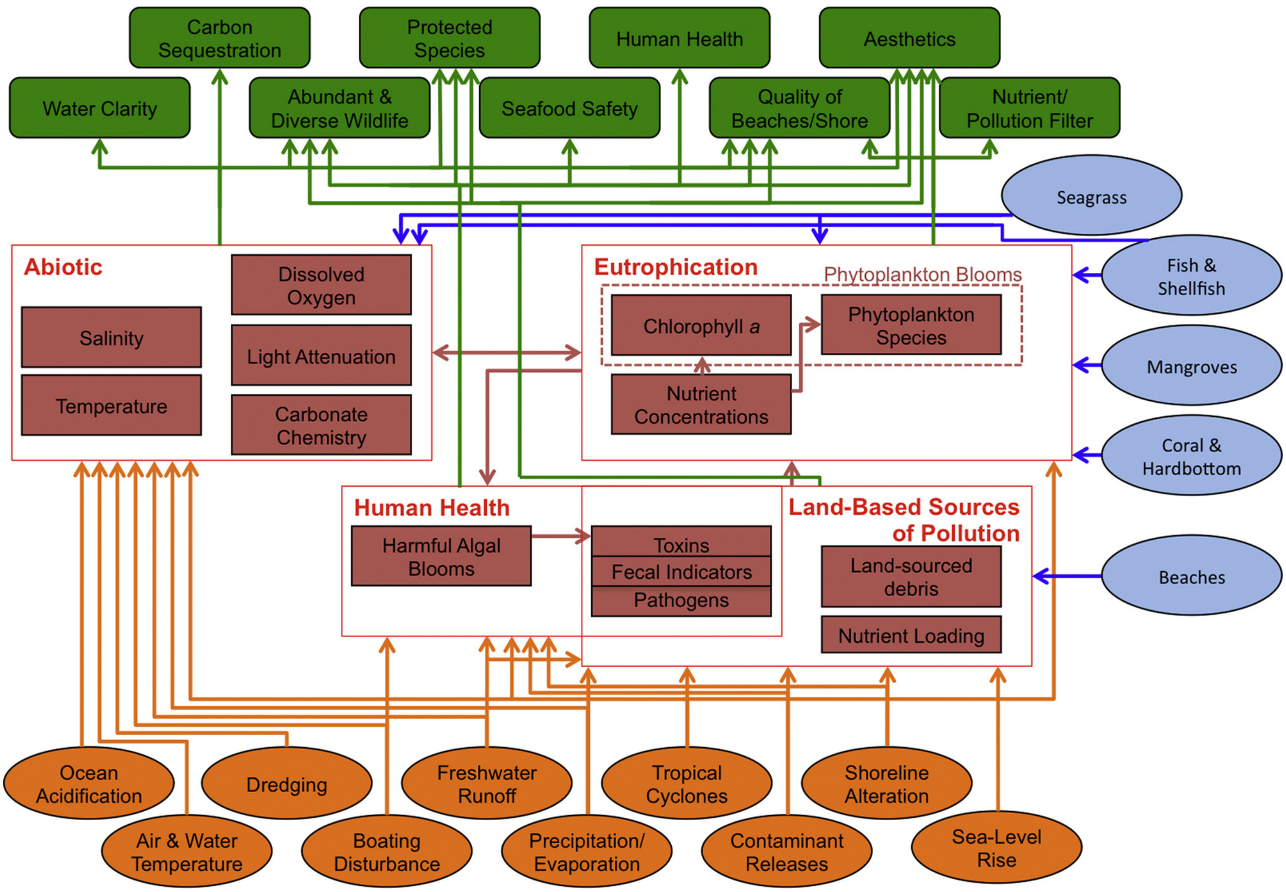

Fig. 5. Water quality integrated conceptual ecological submodel developed to capture the details of the drivers, pressures, ecosystem services, and responses in the ecosystem (Nuttle and Fletcher, 2013a,b,c). The figure illustrates the interconnectedness of the ecosystem and humans as a part of it. Expert opinion was used to develop a diagram representing the ecosystem form and function during workshops.

Table 1
Criteria to guide development of indicators from attributes that we can measure.

Primary criteria
1. Does the indicator provide an integrative measure of the overall status of the ecosystem or of essential ecosystem structures, functions or processes? (Doren et al., 2009; Dale and Beyeler, 2001; Luckey, 2002)
2. Does the indicator relate to ecosystem service(s)? (modified from Feld et al., 2009)
3. Is the indicator relevant to management goal(s)? (Bradley et al., 2010)
4. Is the indicator sensitive to system drivers and pressures? (Doren et al., 2009; Dale and Beyeler, 2001; ICES, 2002)
Data/analysis criteria
5. Is the indicator based upon data that can be generated with accuracy and precision relatively easily and for which there is sufficient existing data to evaluate change going forward? (Doren et al., 2009; ICES, 2002; Dale and Beyeler, 2001; Rice and Rochet, 2005)
6. Is it possible to predict how the indicator will respond to changes in the ecosystem (including societal changes) over management-relevant time scales? (Feld et al., 2009; Dale and Beyeler, 2001)
7. Does the indicator have a response that is easily detectable above the background variability to make it useful in measuring response to management actions or a change in a Pressure that may or may not be a result of management action(s)? (This also means the response signal should be attributable to a change in management or pressure.) (ICES, 2002; Bradley et al., 2010)
Communication
8. Is the indicator understood by managers and the public? (Rice and Rochet, 2005)
9. Does the indicator respond to stress earlier than the rest of the system (i.e., is it a leading indicator?)? (Dale and Beyeler, 2001)
10. How long will it take for the indicator to show a response to possible management actions? (Dale and Beyeler, 2001)
11. Has the indicator been employed effectively either in south Florida or elsewhere? (NRC, 2000)

range of users from those only interested in the broad status of the ecosystem and thus only the most aggregated of indices to those interested in a specific sector within the ecosystem to assess the current status of a specific ecosystem metric (Loomis et al., 2014).

The focal ecosystem components identified in the EBM-DPSER models became the full suite of high-level composite indices required to assess the status of the ecosystem. However, the underlying indicators had to be developed to calculate these indices. Work groups identified at the scoping workshops developed these underlying indicators. They lead indicator development for each state component as well as all relevant human dimensions components of the ecosystem. These work groups were comprised of 2–15 people including topical experts and, where possible, relevant resource managers. Each work group was tasked with selecting indicators based on the MARES indicator criteria and writing a manuscript reporting on the indicator selection process and results (cf. Lirman et al., 2014; Loomis and Paterson, 2014; Marshall et al., 2014; Ogden et al., 2014a,b; Wingard and Lorenz, 2014).

2.3. Risk analysis

The third step in the IEA process was to conduct risk analysis on the ecosystem components and their relationships to one another. This was performed through a two-day scoping workshop at the end of the MARES process that sought to elicit expert opinion to rank the strength of connections between pressures, states, and ecosystem services identified in the EBM-DPSER model for Florida Bay, the Florida Keys, and the Dry Tortugas. The workshop was held on August 22–23, 2012 and 386 questions were posed to 25 regional scientists, managers, and an elected official using keypad polling systems (Cook et al., 2014; Turning Technologies, 2013). The responses were used to gather, analyze, and illustrate consensus on the strength of the model linkages between ecosystem pressures, states, and ecosystem services, and the relative risk of selected ecosystem states and services due to the cumulative impacts from pressures. For a detailed description of this methodology see Cook et al. (2014).

2.4. Evaluating management scenarios

The evaluation of alternatives has been found to be a key feature in the use of conceptual models to support resource management decision making (Tscherning et al., 2012). There are a number of methods that can be applied to evaluate management scenarios with conceptual models (cf. Harwell et al., 2010; Reiter, 2004; Elmer and Riegl, 2014); however, Bayesian Belief Networks (BBNs), or probabilistic models that employ adaptive management and can incorporate consensus based approaches, were selected as a method to test the utility of translating the MARES science to evaluate management scenarios (Nyberg et al., 2006). BBNs were chosen due to their relative ease of use, ability to incorporate qualitative and quantitative data, and visualization features. In addition, BBNs are themselves focused on building consensus consistent with the overall MARES goals. Moreover, BBNs can develop a broader understanding of impacts and range of outcomes, sometimes with limited information from stakeholder perceptions (Cain et al., 1999; Cain, 2001; Lynam et al., 2002). Growing interest in the use of BBNs to develop consensus-based management alternatives, or "reasonable assurance" in the decision making process provoked their use for assessing applicability to evaluating management scenarios and increasing the use of science by resource managers within MARES (Uusitalo, 2007; Lynam et al., 2010; Nyberg et al., 2006; van Dam et al., 2013).

Using responses from the IEA process, a proof of concept BBN was constructed using Netica (Norsys, 2013) software to represent the relationship of ICEM variables and the usefulness of the network in decision making. This exploratory network was constructed using the coral reef and hardbottom CEM from the Southeast Florida Coast (SEFC), with a subset of climate change impacts that were determined to be the most prevalent global driver in the region (Fig. 6) (Nuttle and Fletcher, 2013c; Riegl et al., 2013). The prototype was designed to mimic the CEM model structure with input from MARES participants, coral researchers, and the literature. The prototype was shown to potential endusers (i.e., resource managers) in small-group settings to obtain a first impression of the BBN as a decision support tool. The far-field drivers and pressures selected were "pressures related to climate change and the rising concentration of carbon dioxide in the atmosphere, including the effects of ocean acidification and accelerated sea-level rise" (Nuttle and Fletcher, 2013c). While it was recognized that far-field pressures were typically beyond the jurisdictional boundary of regional management entities, the climate change driver was selected for use in the BBN to investigate what pressures (e.g., sea level, temperature, acidification, etc.) may have the most impact on coral reefs and hardbottom habitats, and which management intervention (e.g.,

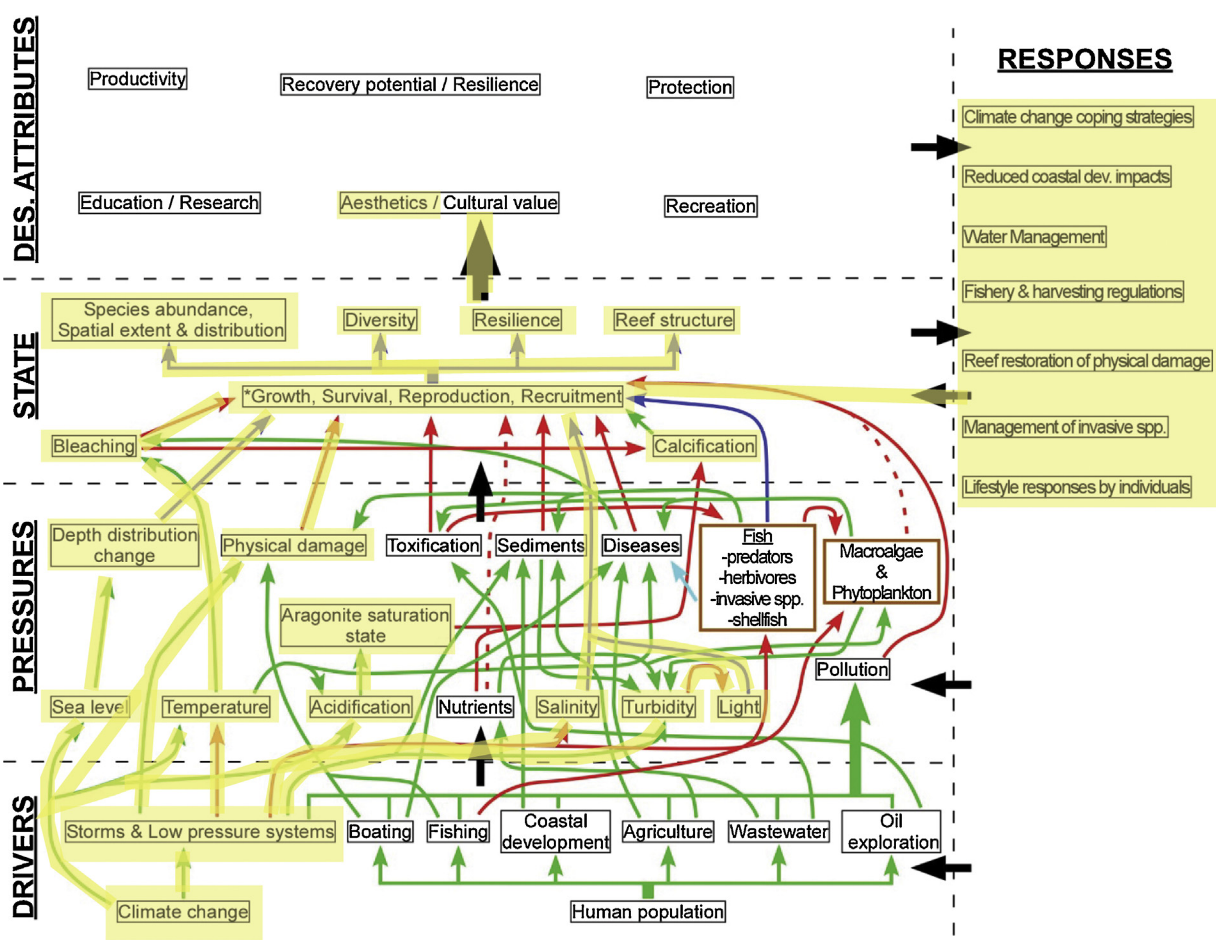

Fig. 6. Climate change impacts of the coral reef and hardbottom habitats of the Southeast Florida Coast conceptual ecological model, highlighted here in yellow, were used to create the Bayesian Belief Network (see Fig. 7). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

reef restoration, water management, etc.) might be used to address the impacts. Thus, BBN scenarios were built for use in promoting awareness of the cascade of impacts to reef ecosystems caused by climate change when communicating with the general public and decision-makers.

The BBN was completed using a step-wise process focused on stakeholder engagement (Cain, 2001). In this way, each activity from the South Florida IEA was incorporated into building the network. Scoping identified the network purpose and provided a comprehensive overview, the ICEM of the region that proved most useful for building the BBN structure, indicators were used to define the nodes in the BBN, and the risk assessment confirmed through expert opinion that the greatest strengths of relationships from ecosystem pressures to states impacting ecosystem services were freshwater delivery to the coastal ecosystems and climate change suggesting the use of climate change in the proof of concept model (Cook et al., 2014).

The BBN presented climate change impacts to the SEFC in a visual format consisting of 18 nodes (boxes) and 25 lines connecting those nodes as detailed in the CEM coral and hardbottom diagram (Fig. 7). The nodes were connected by arrows to illustrate parent–child relationships. These links supported the BBN mathematical model calculating the probabilities of the condition of nodes (e.g., high or low diversity of corals). Working from the bottom of the diagram upwards, and following the EBM-DPSER model, two nodes described the drivers: climate change and storms and low pressure systems. These nodes lacked parents, but collectively had 7 parent–child relationships with nodes representing pressures in the coral and hardbottom CEM. Node values could be manipulated (e.g., frequency of storms being *many* or *few* per year) to measure the cascade of impacts to the network ultimately ending with "aesthetics" being the selected desirable ecosystem attribute for this exercise.

Moving upwards in the model, there were seven pressures (sea level rise, depth distribution change, temperature, physical damage, acidification (measured by pH was combined with aragonite saturation state from the CEM), salinity, and turbidity and light attenuation were joined together). Sea level rise was a parent node using a 2010 reference level, and regional projections of 3–7 in. (2030) and 9–24 in. (2060) (Nuttle and Fletcher, 2013c; SFRCCC, 2011). Sea level rise also fed into one other pressure node (depth distribution change). Depth distribution change was associated with rising sea levels and the ability of corals to grow upwards, retain their vitality at deeper depths, or to see a shift in coral species at deeper depths. Qualitative values (weak, moderate, strong) were assigned to this node because of the uncertainties tied to this change. Temperature parameters selected were determined using one of the protected species of coral, staghorn coral (*Acropora cervicornis*) having quantitative temperature thresholds (Shinn, 2012). Physical damage was generically categorized as *high*, *moderate*, or *little* based on acreage impacted. Ocean acidification was represented by combining aragonite saturation state and pH. The mineral aragonite is available in seawater for use by organisms such as corals to build their skeletons. The saturation state of aragonite affects the availability of the mineral impacting coral growth rates. Lower seawater pH levels result in lower amounts of aragonite available for coral growth. The resulting node reflects qualitative values based on saturation state ranges derived from research: no mineral available for coral growth (no growth (0–2)), same growth rate as today (3–4), and faster growth rate (5+) (Langdon, 2012). Salinity values of 34, 35–39, or greater than 40 ppt were determined from Riegl et al. (2013). Turbidity and light were not consistent in their impacts to corals. Riegl et al. (2013) noted several studies in which coral growth rates both increased and decreased with changes in light penetration to the sea floor associated with turbidity. This node remained part of the BBN because of its inclusion in the CEM with values assigned as *good* or *bad* light levels. It served as another example of how to deal with uncertain variables in the network.

States were addressed next following the structure of the CEM. Bleaching, the expulsion of symbiotic algae from coral tissue, was represented by the presence or absence of this condition in coral colonies. Calcification rates (*high* or *low*) represented the ability of corals to produce calcium skeletons. Growth, survival, reproduction and recruitment were grouped together in the CEM and remained so for the BBN to summarize the overall condition of

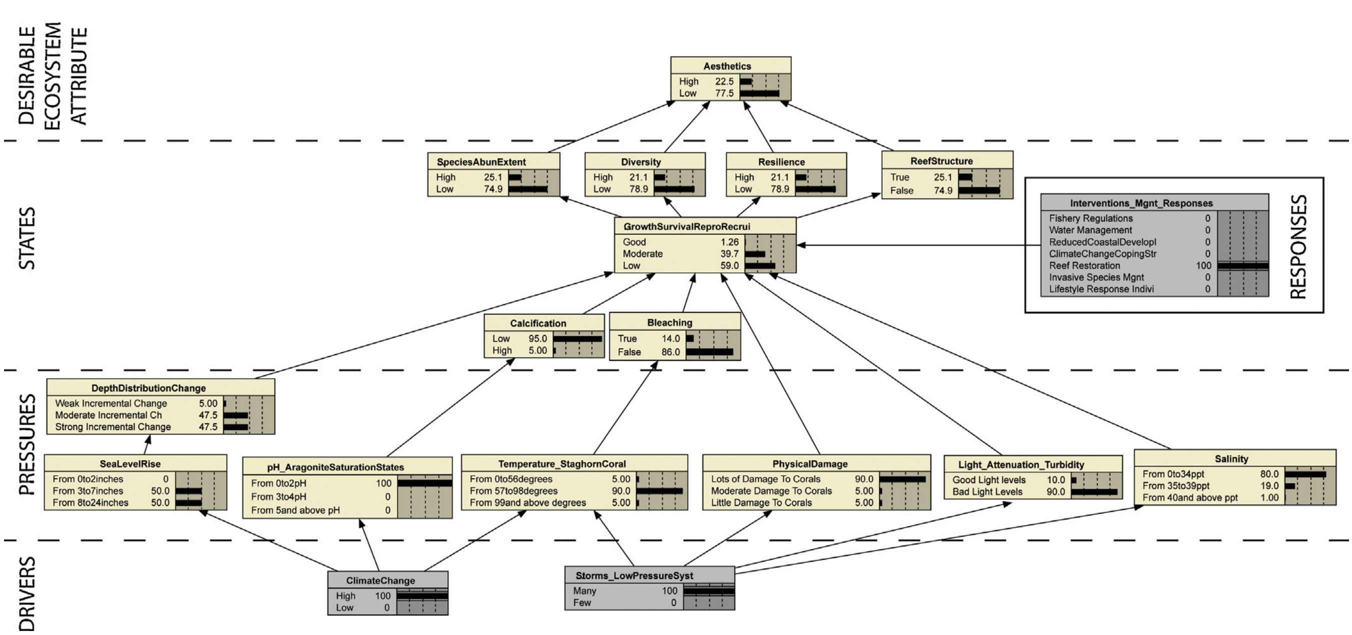

Fig. 7. Bayesian Belief Networks are used to incorporate stakeholder knowledge, values, and preferences in the decision making process. An example was developed to test the utility for applying this method to complement the South Florida IEA process. Climate change impacts to coral reefs and hardbottom habitats were drawn from the conceptual ecological model for the Southeast Florida Coast subregion (see Fig. 6). Drivers, pressures, states, attributes that people care about and management responses were incorporated into the network to illustrate the potential to create and use these networks to test climate impacts and management interventions.

corals. This node fed into four more states (diversity, resilience, and reef structure, and the grouping of species abundance, spatial extent and distribution). These nodes represent measureable attributes that can be used as indicators of reef condition, and are therefore valuable to the BBN in providing qualitative and quantitative information that can be used and updated in scenarios.

Responses, or management interventions identified were included (fishery regulations, water management, reduced coastal development, climate change coping strategies, reef restoration, invasive species management, and lifestyle response by individuals). These were identified by the CEM authors and vetted during document review. The values of the responses were manipulated during scenarios to identify if there were changes to coral reef and hardbottom state or desirable ecosystem attributes (see Table 2).

Desirable ecosystem attributes was the topmost node. Aesthetics was chosen to encapsulate all of the other nodes and values in the network. Riegl et al. (2013) note the importance of aesthetics for recreational and tourism in the region. It was used in the prototype BBN to explore probability values one might place on the state of the ecosystem and effects of management responses.

A table (Table 3) was created to assign conditional probabilities for every node and combination of nodes. This task was performed

Table 2
Prototype BBN indicators, units, and states for the southeast Florida coral reef and hardbottom conceptual ecological model.

Node	Indicator	Unit	State	Reference
Storms_LowPressureSystems	Number of storm events per year based on average from 1996 to 2009	Number of storms	13+ 12 ≤11	Neumann et al. (1999) and Nuttle and Fletcher (2013c)
ClimateChange	Presence or absence of climate change impacts	Qualitative	High Low	
Sea level rise	Sea level based on 2010 regional assessment and projections for 2030 and 2060	Inches	0–2 3–7 9–24	SFRCCC (2011)
DepthDistributionChange	Incremental change based on current sea level and presence/absence of stony corals	Qualitative	Weak incremental change Moderate incremental change Strong incremental change	Riegl et al. (2013)
pH_AragoniteSaturationSate	Saturation state of aragonite (carbonate mineral) in seawater tied to rates of calcification based on level of pH of oceans caused by uptake of anthropogenic CO_2 from atmosphere	Qualitative (state)	No growth (no available 0–2) Same rate as today (3–4) Faster growth rate (aragonite available (5+))	Kleypas et al. (1999) and Langdon (2012)
Temperature	Survival temperature thresholds for staghorn coral (Acropora cervicornis)	°F	0–56 57–98 99+	Shinn (2012) and Mayor (1914)
PhysicalDamage	Based on the extent of damage caused by natural (storms) or human (boats) activities	Qualitative	High-impact reef structure Moderate-mix of little and high Little-superficial	Ault et al. (1997), Chiappone et al. (2005), Lirman et al. (2010) and Riegl et al. (2013)
Light_Attenuation_Turbidity	Based on clear, turbid free water allowing light to penetrate to depth for coral growth	Qualitative	Good Bad	Dodge and Aller (1974) and Riegl et al. (2013)
Salinity	Average seawater content (36 ppt) and stony coral thresholds	ppt	0–20 25–40 40+	Edmondson (1928), Jokiel and Coles (1977) and Riegl et al. (2013)
Bleaching	Presence or absence of bleaching, expulsion of symbiotic dinoflagellates caused by warm or cool temperatures	Boolean	True False	Van Oppen and Lough (2008) and Riegl et al. (2013)
Calcification	Current acidity rates of seawater and the ability of coral to grow	Qualitative	Low High	Kleypas et al. (1999), Andersson et al. (2005), Cohen and Holcomb (2009) and Riegl et al. (2013)
Growth, survival, reproduction, recruitment	Current baseline in Atlantic/Caribbean reef systems ~3–6%	Qualitative	High Moderate Low	Riegl et al. (2013)
Management interventions	Current options identified for responding to changes in coral reef and hardbottom habitats		Fishery regulations Water management Reduced coastal development Climate change coping strategy Reef restoration invasive species management Lifestyle response by individuals	Riegl et al. (2013)
SpeciesAbunExtentDist	Estimated percent cover of stony coral over southeast Florida substratum	Qualitative	High Low	Gardner et al. (2005) and Riegl et al. (2013)
Diversity	Number of species/taxa and genetic level	Qualitative	High Low	Connell (1978) and Riegl et al. (2013)
Resilience	Ability of system to absorb, resist or recover from disturbances or to adapt to change while continuing to main essential functions and processes	Qualitative	High Low	Riegl et al. (2013)
ReefStructure	Presence of three-dimensional geomorphic features	Boolean	True False	Riegl et al. (2013)
Aesthetics	Diverse, productive, healthy coral reef habitats	Qualitative	High Low	Riegl et al. (2013)

Table 3
Conditional probability table (CPT) for the output node "Aesthetics" in relation to parent nodes "SpeciesAbunExtentDist," "Diversity," Resilience," and "ReefStructure.".

SpeciesAbunExtentDist	Diversity	Resilience	ReefStructure	High	Low
High	High	High	True	100	0
High	High	High	False	90	10
High	High	Low	True	90	10
High	High	Low	False	80	20
High	Low	High	True	80	20
High	Low	High	False	70	30
High	Low	Low	True	70	30
High	Low	Low	False	60	40
Low	High	High	True	40	60
Low	High	High	False	20	80
Low	High	Low	True	10	90
Low	High	High low	False	5	95
Low	Low	High	True	5	95
Low	Low	High	False	5	95
Low	Low	Low	True	5	95
Low	Low	Low	False	0	100

using knowledge from the development of the CEM reports and input from multiple stakeholder meetings. The probabilities associated with each node in the toy model were assigned as estimates and were not vetted for accuracy. Probabilities reflected a general outcome where 'high' or 'true' conditions of coral growth, survival, reproduction, and recruitment would result in higher esthetic values, and 'low' or 'false' conditions resulted in lower esthetic values. The outputs were intended to illustrate the capabilities and limitations of the BBN and scenario evaluation outputs but require further input for use in management decision making. Once the table was completed, a series of sensitivity analyses were run using the Netica software (Norsys, 2013). This analysis illustrated the influence of other nodes within the network on the selected node. Four analyses were performed, two for aesthetics and two for growth, survival, reproduction and recruitment. Scenarios examined changes resulting from climate change (*yes* or *no*) in combination with storms and low pressures systems (*many* or *few*) using the reef restoration management response.

2.5. Communications

As MARES central goal included the improved use of science by resource management, communications that would aid in the transfer of science to management were an integral component of the program. Communications were developed using stakeholder input from both technical experts and resource managers. Products consisted of printed materials, Internet sites, and interpersonal interactions. Project participants and the resource management community in South Florida confirmed these types of products were appropriate mechanisms to convey information to managers during a scoping exercise. As a result, this communications strategy was pursued to transfer science to managers. Social media was added to the Internet-based products and stronger emphasis placed on developing fact pages to highlight regional and topical components of the ecosystem.

2.5.1. Printed materials

Printed materials were created for use in a variety of settings with the overarching goal to inform the target audience about the IEA effort and its findings. Reports, fact pages, diagrams, and posters were created to meet target audience needs. Fact pages in particular were developed on a regional and topical basis for decision-making and resource managers.

First, the project planning team identified a variety of manager types. Then, the team outlined several kinds of printed materials each manager type would be most likely to use. The materials were created by committee and incorporated data, images, and summary text. The printed materials were then refined through engagement with the targeted management type. Printed materials were identified at the beginning and throughout the project to meet the needs identified by the target audience and as opportunities to share information. Materials were distributed in-person by project partners at meetings throughout South Florida.

2.5.2. Internet-based products

Internet-based products were developed to share project updates and information. A webpage (www.sofla-mares.org), document management system, Facebook, and blog were produced and electronic correspondence using listservs was maintained throughout the project period. The use of Internet-based products was undertaken to encourage interactions with managers and stakeholders and also to reach a broader audience. The website created an Internet presence and established a consistent location for access to meeting announcements, reports, and project contacts. A document management system was designed as a repository for all project documents and reference materials and to share ideas among principal investigators and partners. Two listservs, or email discussion groups were created, one for principal investigators, the other was a moderated list for the public. As the project evolved, a Facebook page, and a blog site were built to improve the awareness of the project and to further discussions among the researchers, managers, and interested public. Google Analytics were used to determine the frequency of visits to the website, Facebook page, and blog.

2.5.3. Interpersonal communications

Formal and informal interactions during workshops, focus groups, meetings, and lunchtime sessions helped established new professional relationships. Many of the principal investigators, especially those from the Florida Keys and Dry Tortugas subregion, worked together since the start of an extensive regional restoration project in the late 1990s. Interpersonal communications occurred among this network of individuals during the multitude of restoration-related meetings and continued with the introduction of MARES in late-2009. In addition, conferences and regional meetings afforded the opportunity for colleagues to interact and get to know one another.

3. Results

3.1. Scoping

MARES conceived and assembled the first comprehensive, science-based consensus for the marine and coastal ecosystem of South Florida through the development of conceptual diagrams, models, and indicators. Scoping served as a platform to conduct this synthesis by building consensus on ecosystem structure and function, diagnosing participant needs (some of whom were managers and NGOs), and creating a shared responsibility for learning among project leaders and participants (Etling, 1993; Kleis et al., 1973). In the case of South Florida, workshops elicited participant opinion and generated a scientific consensus on the fundamental regulating processes of South Florida's marine and coastal ecosystem (Nuttle and Fletcher, 2013a,b,c). Group learning opportunities materialized beyond initial expectations and included exploration for integrating ecosystem components, improved comprehension of specific elements of the ecosystem from specialists, and most prominently with the introduction of human dimensions science into the project (Kelble et al., 2013). Hungerford and Volk (1990) illustrated the process for "environmental citizenship behavior" and how it evolved over time beginning with individual awareness, and then leading to

Table 4
Science communications products developed to transfer science to management and to promote stakeholder engagement.

Science communication product	Description	Usage
1 Project brochure	Two-page overview of the project goals, partners, and process used to complete the effort. Provide project overview with background information; reference to access Web page	Observations reflect use during workshops and meetings in the region
3 Posters	Themed posters illustrating the overall project, process, and science	Observations reflect the posters gained the attention of conference participants and interested public; limited audience, but effective in establishing a presence at conferences and building awareness that led to continued interactions with projects outside of the geographic scope of south Florida; used during ecosystem restoration and human dimensions conferences helpful in the development of the socio-ecological element of the project
3 Fact pages	Two-page overview with colorful imagery and limited text describing individual components of the ecosystem designed for use by specific segments of the management community and geographic scope	Observations reflect fact pages were shared (most often in electronic format) among the project partners with limited use at the time of this report. The fact pages in two geographic sub-regions could be used more frequently in the future as part of stakeholder engagement and a management plan review
10 White papers	Topical summaries and findings written in a standardized format	Observations reflect white papers were used during workgroup sessions and as reference materials in preparation for workshops and meetings
3 Technical memorandums	ICEM workshop reports	Observations reflect the memorandums serve as reference materials in the decision-making process and science synthesis
15 Journal articles	Peer-reviewed publications authored by project investigator	Under development at the time of this publication. Intended to be used to disseminate MARES findings to a broad audience and science managers
Document Management System (DMS)	Web-based clearinghouse for all project documents. Computer software to manage documents tied to project	Used by project team to share and archive documents
Website	Web page (www.sofla-mares.org) released on Thursday, November 17, 2011 and revised on May 1, 2012	Serves as a Web presence and resource to post meeting announcements and documentation for the worldwide audience. The majority of web users downloaded documents (Google Analytics, 2013). From the release date until April 17, 2013, the total visits to the page was 2582. The majority of visits were from Miami, Florida USA (15%) and Ottawa, Canada (5%), Followed by Gainesville, Florida (4%), Silver Spring, Maryland (4%), and Tallahassee, Florida (3%). Those users looked on average at three or four pages on the website with 77% of those visiting the home page, followed by 4% visiting the document downloads page and organization page
Listserv	E-mail service for group announcements and exchanges: principle investigators (mares_pi-list@lists.rsmas.miami.edu) and interested public (mares-list@lists.rsmas.miami.edu)	Served as a one-way mechanism to deliver meeting announcements with very little ancillary information sharing. The MARES PI list contained 61 participants, and the MARES project list 186. All participants were added by request or due to their affiliation as a PI on the project. From August 5, 2009 there were 43 Emails on the MARES PI list, and 25 on the general list starting on November 12, 2009. The majority of Emails were sent by project leaders, with only three messages being sent by list members during the project period
Facebook	Social media site released on March 4, 2012 (http://www.facebook.com/South.Florida.MARES) Used as information exchange and for presence in social media	Initial usage reflects 'likes' from three Florida cities Miami, Fort Lauderdale, and Key Largo (June–July 2012), and then briefly changed to Miami, Florida, and two cities in Mexico, Ciudad Victoria, Tamaulipas, and Mexico City, Distrito Federal (July–August 2012). From August 2012 to present, the greatest number of visitor home locations were Miami, Florida (10%), Milwaukee, Wisconsin (9%), and Mexico City, Distrito Federal, Mexico (6%). On April 20, 2013, the page had 658 'likes' and the page was most active between July 2012 and September 2012. During this time, MARES announced the August 22–23 manager's workshop, posted preliminary results of that meeting, and also placed an advertisement on Facebook to encourage use of the site (Facebook Analytics, 2013)
Blog	Social media site released on March 29, 2012 and is revised frequently with updated reports, diagrams, and summaries. (http://www.maresblog.org/) Created to foster further online communications and interactions among interested groups and individual viewers	The majority of users visited pages with project documents (Google Analytics, 2013). From the release date until April 18, 2013, the total visits to the page was 1939. The majority of visits were from Ottawa, Canada (8%), Gainesville, Florida, USA (8%) and Miami, Florida USA (7%). Those users looked on average at one to two pages on the blog with 52% of those visiting the blog entering via the main page, followed by 8% visiting the Florida Keys/Dry Tortugas Integrated Ecological Model page, 7% visiting workshop read ahead materials (Everglades National Park meeting), and 6% viewing the introduction to the MARES project page. The highest use days (page views) occurred prior to MARES workshops and meetings, and project team update announcements to 'check the blog'

ownership and empowerment (NOAA/CSC, 2007). In this way, each participant, as a scientist, manager, or interested party, engaged in shared learning and the open dialog that contributed to achieving the project goal.

3.2. Indicators

Indicators were developed to determine and convey whether an ecosystem is approaching sustainability and delivering desired levels of ecosystem services that capture the status of both the natural and societal aspects of the system. Consistent terminology for both natural system and human dimensions indicators were defined using an iterative process during workshops and work group meetings, and vetted with the larger participant audience during document development. A hierarchical approach was used to identify a range of indicators. The hierarchical approach to developing consistent indicators is described in detail in Loomis et al. (2014). At the lowest level were data or measurements of one or more variables. The highest level was comprised of an aggregated composite index used to define overall ecosystem status. The highest-level indices were developed using ICEMs and were generally either broad natural science system components (e.g.,

Table 5
Proof of concept BBN sensitivity analysis results "Aesthestics" node based on scenarios using *high* and *low* "ClimateChange," *many* and *few* "Storms_LowPressureSystem," and *reef restoration* "Intervention_Mgnt_Response" based on Fig. 7. The nodes are listed as a percent value in order of greatest to least influence on "aesthetics" with high climate impacts (left column) and low climate impacts (right column).

Node	%	Node	%
SpeciesAbundExtentDist	61.1	GrowthSurvivalRepro	49.1
GrowthSurvivalRepro	48.5	Diversity	28.6
Diversity	22.6	ReefStructure	12.9
ReefStructure	21.9	Bleaching	9.8
Resilience	19.1	Resilience	9.36
Bleaching	5.35	Temperature_Staghorn	3.66
Temperature_Staghorn	3.13	DepthDistributionChange	2.78
Salinity	1.14	Light_Attenuation_Turbidity	0.567
DepthDistributionChange	0.77	SeaLevelRise	0.156
Light_Attenuation_Turbidity	0.1	PhysicalDamage	0.135
SeaLevelRise	0.08	Calcification	0.0977
PhysicalDamage	0.007	pH_AragoniteSaturation	0.000137
Calcification	0.003	SeaLevelRise	0
Interventions_Mgnt	0	ClimateChange	0
Storms_LowPressureSys	0	Storms_LowPressureSystems	0
pH_AragoniteSaturation	0	Temperature_Staghorn	0
ClimateChange	0	Interventions_Mgnt	0

water column, coral and hard-bottom) or ecosystem services (e.g., recreation quality) that were themselves composed of a number of lower level indicators. Indicators were developed or already existed for economic human dimensions (Johns et al., 2014), non-economic human dimensions (Loomis and Paterson, 2014), coastal wetlands (Wingard and Lorenz, 2014), corals (Lirman et al., 2014), marine birds (Ogden et al., 2014a,b), fish (Ault et al., 2014), oysters (Volety et al., 2014), seagrass (Madden et al., 2009), and the water column (Kelble et al., in preparation). Although beyond the scope of the MARES project, further efforts can incorporate these indicators into ecosystem report cards that document trajectories toward (or away from) a sustainable condition that delivers the desired levels of ecosystem services.

3.3. Risk analysis

Risk analysis using the conceptual models developed during MARES and participant input are described in detail in Cook et al. (2014). Participant opinion gathered during a workshop resulted in fish and shellfish, protected species, and marine birds ranking as the most at risk of the ecosystem states. The highest ranked pressures that contributed to the largest degradation of ecosystem services were freshwater delivery, temperature effects of climate change, and impacts of climate change on weather. The most at risk ecosystem services were existence of a natural system, pristine wilderness experience, and non-extractive recreation. The risk analysis workshop results were the first quantitative assessment of the ICEM components and further analysis to their utility in management are being explored.

3.4. Bayesian Belief Network

The prototype BBN captured EBM-DPSER components using quantitative and qualitative information obtained during the IEA process to examine causal probabilities and sensitivity analysis among selected components. Overall, more intense climate impacts resulted in lower quality coral reef and hardbottom aesthetics. For periods with more intense climate impacts, the probabilities of "aesthetics" being *high* quality was 22.5%, and *low* quality 77.5%, and for periods with lower climate change impacts, probabilities for *high* quality were 50.4%, and *low* quality were 49.6%. Sensitivity analysis showed that the nodes with the most influence on the "aesthetics" outcome were parent nodes: diversity, resilience, reef structure and the grouping of species abundance, spatial extent and distribution (Table 5). For high climate change impacts the probabilities for the state indicator "growth, survival, reproduction, recruitment" being were *good* 1.26%, *moderate* 39.7%, and *low* 59% showing low coral health and growth in these conditions. For periods with less climate change impacts, the probabilities for this indicator changed to *good* 12.1%, *moderate* 71.7%, and *low* 16.2% validating reef conditions would be better during times with less climate impacts. Sensitivity analysis for both high and low climate impacts showed that child nodes within the state element of the CEM had the most influence on this indicator: reef structure, species abundance, extent and distribution, aesthetics, diversity, resilience and bleaching (Table 6). In general, the network validated MARES discussions about climate influencing ecosystem attributes that people care about, the limitations of management responses to the global climate change driver, and the network provided numeric values to evaluate indicators. Ten individuals responsible for resource management or supporting management decisions viewed the tool and most expressed an interest in continuing to build and refine the network, because they felt it could help inform their decisions. This is evidence that the BBN can be used for further stakeholder discussions and evaluating scenarios to transfer scientific knowledge into management.

3.5. Communications

Thirty-five science communications were produced to document and synthesize information for managers and stakeholders (Table 4), and numerous information exchanges took place in the form of workshops, meetings, writing sessions, electronic exchanges, and conversations over the four-year project period. Six conceptual diagrams, 3 ICEMS, 19 state CEMS, greater than 50 indicators, 20 indices, and one risk analysis were completed with input from 124 participants, many of those repeatedly engaged in workshops and writing activities.

The IEA process resulted in the formation of an informal social network of scientists, resource mangers, and interested parties located throughout South Florida that is used to exchange information and promote the use of science to inform decision making. While no formal evaluation was performed to document the utility of the different communication strategies, observations by staff made during workshop participation, information requests, and project partner feedback reflected positively on the outputs. The website had 2582 visits from 17 November 2011 to 17 April 2013. The Facebook page had 658 'likes' from 4 March 2012 to 20 April

Table 6
Proof of concept BBN sensitivity analysis results "GrowthSurvivalReproRecruitment" node based on scenarios using *high* and *low* "ClimateChange," *many* and *few* "Storms_LowPressureSystem," and *reef restoration* "Intervention_Mgnt_Response" based on Fig. 7. The nodes are listed as a percent value in order of greatest to least influence on "GrowthSurvivalReproRecruitment" with high climate impacts (left column) and low climate impacts (right column).

Node	%	Node	%
ReefStructure	40.4	ReefStructure	26
SpeciesAbunExtentDist	40.4	SpeciesAbunExtentDist	26
Aesthetics	35.2	Aesthetics	25.1
Diversity	32.8	Diversity	24.8
Resilience	32.8	Resilience	24.8
Bleaching	9.4	Bleaching	9.32
Temperature_Staghorn	5.45	Salinity	7.2
Salinity	2.01	DepthDistributionChange	1.7
DepthDistributionChange	1.55	Light_Attenuation_Turbidity	0.5
Light_Attenuation_Turbidity	0.17	PhysicalDamage	0.48
SeaLevelRise	0.13	Calcification	0.3
PhysicalDamage	0.01	pH_AragoniteSaturation	0.0004
Calcification	0.01	Temperature_Staghorn	0
Interventions_Mgnt	0.007	SeaLevelRise	0
Storms_LowPressureSys	0	Interventions_Mgnt	0
pH_AragoniteSaturation	0	Storms_LowPressureSys	0
ClimateChange	0	ClimateChange	0

2013. The greatest use of the Facebook page occurred prior to workshops and when preliminary findings were posted. The blog also experienced highest usage prior to workshops, meetings and project team updates and had 1939 visits from 29 March 2012 to 18 April 2013 (Table 4).

4. Discussion

MARES was a resource intensive four-year project that made significant progress toward implementing an IEA in South Florida. However, this IEA still has not assessed the current status of the ecosystem to determine if it is sustainable and delivering desired levels of ecosystem services and has yet to fully evaluate management scenarios. Thus, it has yet to complete a single iteration of the IEA framework and as such is still in its infancy. The scoping, indicator development, and risk analysis represent a consensus developed from participant opinion, resource managers, and NGOs accomplishing one of MARES primary objectives. While this effort was comprehensive and inclusive, it forms only the beginning of an adaptive process necessary to provide the scientific support for EBM of South Florida's coastal and marine system. Despite being in its infancy, the south Florida IEA process has already begun to increase the use of science by resource managers. It has increased communication between scientists, NGOs, and resource managers as exemplified by the development of consensus conceptual diagrams, models, and indicators. Moreover, the risk analysis and BBN were both developed in close partnership with the resource management agencies, which had input on the design, hypotheses, and implementation from their conception to their completion in hopes that this would increase their utility to relevant resource management decision makers.

At this stage, monitoring and integrative tools emerge to inform, challenge and adapt the current system understanding into adaptive and responsive management options. Following with our example BBN, scenarios were used for illustrative purposes to show how the network can provide useful opportunities for further dialog and to evaluate potential future scenarios including pending management decisions. The BBN demonstrated that even with simplistic yet plausible initial data, the results of the network model are consistent with our scientific understanding and help spotlight relationships and potential challenges in adaptive management.

The proof of concept BBN proved useful in examining the ICEM components in an iterative format and assessing management interventions in an adaptive capacity. The network lacked any new information or insights compared to the ICEM from which it was designed and should be taken into consideration when reviewing the results. Further exploration of the BBN as a tool for transferring science to management is warranted. It is unclear if other scenario evaluation tools could further the IEA process since this was the only method used during the MARES project. However, the network shows promise as a method to assimilate and address uncertainties in environmental decision making, screen management or policy options, and identify knowledge gaps as described by Cain (2001). The South Florida IEA network developed by MARES was essential to successfully testing (1) if a BBN could be designed from the ICEMs and (2) the utility of the model for endusers. This preliminary BBN met the categories of evaluation criteria developed by Lynam et al. (2007) which state "the tool must (1) support communication and learning between the insiders and outsiders who are using the tools; (2) be adaptable for implementation in various decision-making contexts for use by diverse users, including those at the local level; and (3) produce data and information that are useful and valid as a basis for decision-making or can be used for further analyses."

The results of the experimental BBN showed that little could be done to improve reef aesthetics as a result of intense climate impacts. The sensitivity analyses performed helped identify factors that may be most useful to managers in deciding what action to take to reduce or enhance the aesthetics of coral reefs and hardbottom in southeast Florida. In addition, the network can be used to test indicators to determine which indicators are more sensitive in assessing the aesthetics of the ecosystem. These concepts can be further explored by manipulating the structure of the prototype BBN, for example, management interventions might link directly to multiple drivers, pressures, and states, and expanding the BBN to include the human population elements of the coral and hardbottom CEM.

MARES provided several new insights for organizing and implementing long-term ecosystem management activities and IEAs. The participatory consultative approach was successful in catalyzing new ideas for research, monitoring, and management actions that emphasize human dimensions science, including well-being (Loomis and Paterson, 2014). Input from knowledge actors (e.g., researchers, planners, and managers) was instrumental in all aspects of the project and their commitment to participate in the multi-year effort critical to the success of the IEA. The process helped develop new products, such as diagrams of the South Florida ecosystem that assist in conveying information about the form and function of the environment. These concepts can be used to develop new ways of managing that truly incorporate stronger integration of biophysical and human dimensions science. Lastly, the evolution of a coordinated network of resource managers, scientists, and NGOs that have developed a consensus on ecosystem structure and function cannot be overstated. This network has already shown an increased ability to transfer scientific knowledge to management as demonstrated by the BBN described herein, and other related efforts described by Elmer and Riegl (2014) and Cook et al. (2014). The development of additional communications in MARES to help transfer this knowledge to management improved the utility of IEA products and has resulted in the use of IEA products in ongoing management activities, such as a scoping exercise for southeast Florida and science communications in the Florida Keys and southwest Florida.

Additional insights from the project included the following:

Plan for evaluation: Print, Internet, and information exchanges in general appear to be valuable to the multitude of managers involved in the project, but reporting for these was not consistent. Understanding how effective these products are is difficult without conducting a formal needs assessment that includes an evaluation method at the beginning of the project (NOAA/CSC, 2003, 2009; Witkin and Altschuld, 1995). This process aids in explicitly identifying a target audience and their needs, and a process to evaluate measurable outcomes of the effort.

Build upon existing networks: Informal communications are difficult to evaluate, but often are critical in building a network of partners who work together to achieve a common goal. The South Florida IEA project is no exception to this concept. In 1993, a regional water monitoring and management initiative began and in part, evolved into a larger ecosystem restoration effort that included frequent interactions among researchers and managers attending workshops and meetings. The network of individuals formed over the past 20 years appears to foster a level of respect or trust for colleagues with a common interest in South Florida's ecosystem that benefitted the MARES project.

Plan for adaptation: Wicked environmental problems are complex, and often require complex solutions (Churchman, 1967; Rittel and Webber, 1973; Xiang, 2013). The solutions are often adaptive as new information is added into the decision-making process. Fluidity in project planning must be recognized and accounted for in the adaptive process.

Pictures tell stories: Conceptual diagrams proved useful in synthesizing science into a visual format for multiple purposes. The process of developing the conceptual diagrams resulted in shared vision with participants coalescing around one easy-to-interpret representation of a complex ecosystem. Use of diagrams in presentations, print materials, and the number of requests to obtain images exceeded that of any other products from the project.

Consensus building helps explore new ideas and concepts in a safe place: Participants with varied backgrounds observed and discussed the cause-and-effect relationships found in the ecosystem during several steps in the IEA process. The result was the development of a single document synthesizing the environment using the Driver, Pressure, State, Ecosystem Services, and Response for the ecosystem, and 19 state ecological submodels (Nuttle and Fletcher, 2013a,b,c). Workshop discussions of human dimensions science, especially the non-economic values, brought to the forefront a realization that a broader view of this field of science was necessary in the project, and a work group was created to further this element of the project.

Integrative tools are required to move forward: Goldston (2009) states that science is one factor in the decision-making process, noting that typically, the problem is not a lack of information, rather difficulty in separating the policy questions from the science questions, and the interplay of values and risk in decision making. BBNs were helpful in integrating ICEM components. The ability to build a network with qualitative and quantitative information is useful to begin adaptive management discussions and to explore optimal management responses. The BBN is a promising decision support tool that will be expanded for further analysis and use in the IEA process.

5. Conclusions

The IEA process used in South Florida was helpful in framing the interconnected multidisciplinary components of the system. The use of tools, such as the conceptual diagrams in building consensus and describing the ecosystem to non-technical audiences and BBN management alternatives, can be helpful in engaging the management community and stakeholders in the EBM discussion. The IEA process is useful and all three parts: people, process and tools, needs consideration, this effort supported the importance of consensus-building process to truly implement the EBM science into decision-making (Kiker et al., 2005).

The IEA process was successful in building consensus focused on a comprehensive synthesis of the regional marine and coastal ecosystem as well as in contributing to the transfer of science to a variety of target audiences including managers as evidenced by the vast array of products produced and the number of visitations to project websites. While there was no single decision-making outcome that was directly attributable to the project, several benefits were identified by participants: a foundation to incorporate marine and coastal elements into regional restoration and a larger ecosystem assessment; the importance of a consensus-based approach to integrate human dimensions science in what many consider ecologically focused projects; and, it forged relationships to include complex, multivariate results into the decision making process among multi-agency, non-profit, and academic institutions in the region. In addition, an informal EBM-IEA network was created and was valuable to obtain feedback on the needs and uses of ecosystem information by managers. The EBM-IEA foundation and MARES network continues as part of the Gulf of Mexico IEA and management planning.

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