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Using Integrated Ecosystem Assessments to Build Resilient Ecosystems, Communities, and Economies

Ellen Spooner[a], Mandy Karnauskas[b], Chris J. Harvey[c], Chris Kelble[d], Judith Rosellon-Druker[e], Stephen Kasperski[f], Sean M. Lucey[g], Kelly S. Andrews[c], Stephen R. Gittings[h], Jamal H. Moss[f], Jamison M. Gove[i], Jameal F. Samhouri[c], Rebecca J. Allee[j], Steven J. Bograd[k], Mark E. Monaco[l], Patricia M. Clay[g], Lauren A. Rogers[f], Anthony Marshak[n], Supin Wongbusarakum[o], Kathy Broughton[h], and Patrick D. Lynch[m]

[a]ECS Federal LLC in support of Office of Science and Technology, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA; [b]Southeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Miami, Florida, USA; [c]Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington, USA; [d]Atlantic Oceanographic and Meteorological Laboratory, Oceanic and Atmospheric Research, National Oceanic and Atmospheric Administration, Miami, Florida, USA; [e]College of Fisheries and Ocean Sciences, University of Alaska Fairbanks, Fairbanks, Alaska, USA; [f]Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Seattle, Washington, USA; [g]Northeast Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Woods Hole, Maryland, USA; [h]Office of National Marine Sanctuaries, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA; [i]Pacific Islands Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, Hawai'i, USA; [j]Office for Coastal Management, National Ocean Service, National Oceanic and Atmospheric Administration, Stennis Space Center, Mississippi, USA; [k]Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Pacific Grove, California, USA; [l]National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA; [m]Office of Science and Technology, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA; [n]CSS, Inc. in support of National Centers for Coastal Ocean Science, National Ocean Service, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, USA; [o]The University of Hawai'i Sea Grant College Program, Pacific Island Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Honolulu, Hawai'i, USA

ABSTRACT

Science-based natural resource management is necessary for agencies to effectively meet their goals and mandates. However, this scientific basis needs to be advanced and evolved with ecosystems experiencing unprecedented events that challenge conventional management frameworks. Effectively managing marine resources and achieving agency missions requires more than meeting independent mandates and managing individual resources as chronic stressors overwhelm conventional management frameworks. Global science organizations are transitioning to interdisciplinary and holistic research to integrate human well-being as a key outcome. The United States' principal federal agency tasked with managing coastal and marine ecosystems is the National Oceanic and Atmospheric Administration (NOAA). NOAA's

KEYWORDS
Ecosystem-based management; integrated ecosystem assessment; NOAA integrated ecosystem assessment program; resilient ecosystems

CONTACT Ellen Spooner ellen.spooner@noaa.gov NOAA National Ocean Service, National Marine Fisheries Service, cube #12340, 1315 East West Highway, Silver Spring, MD, 20910, USA

vision is "healthy ecosystems, communities and economies that are resilient in the face of change". NOAA adopted the Integrated Ecosystem Assessment (IEA) approach to conduct the collaborative science necessary for ecosystem-based management. IEAs have been employed for over a decade to develop science, tools, and collaborations that address complex ecosystem challenges and make progress toward NOAA's vision. This paper demonstrates, through case studies, how scientists, stakeholders, and managers build trust and meaningful relationships from the IEA approach. These case studies further demonstrate how the IEA approach can be adapted to various geographic and management scales to build trust with partners and provide the ecosystem science, including social science, required to build resilient coastal ecosystems, communities, and economies.

Introduction

Marine ecosystems and the people that rely upon them are facing complex challenges (Berkes 2015). Stressors to marine ecosystems include, but are not limited to marine heatwaves, harmful algal blooms, overfishing, wastewater pollution, coastal development and eutrophication. Amidst these stressors, managers are challenged with ensuring marine ecosystems produce the services that support community, economic, and social well-being. Social or human well-being can have many definitions, but in this context refers to non-material benefits and values marine ecosystems provide to communities (Leong et al. 2019). Services provided by marine ecosystems include recreational opportunities (Dwyer 2018), consumption of seafood (FAO 2018), coastal development (Chi and Ho 2018), and protection against coastal storms (Javeline and Kijewski-Correa 2019). Stressors to marine ecosystems negatively impact the ability of marine ecosystems to provide these services and managers must then adapt to unprecedented conditions (Oliver et al. 2019, Wilson et al. 2018).

Addressing these complex challenges requires that organizations use more comprehensive science (Lynch et al. 2015). A key attribute for a scientific framework to more comprehensively contribute to building healthy and resilient ecosystems, communities, and economies is adaptability (Plummer and Armitage 2007). Many natural resource management agencies across the globe are implementing ecosystem-based management (EBM) (Garcia et al. 2003, NMFS 2016a, Pedreschi et al. 2019). EBM is an adaptable form of management that brings together natural and social scientists, stakeholders and resource managers in both the science and management-decision process to build meaningful relationships and recognize the full array of interactions within an ecosystem, including humans, rather than just considering single issues. The transition to EBM is ongoing and more advanced in terrestrial than marine ecosystems (Layzer 2008), but is allowing scientists to understand problems from multiple perspectives, generate novel insights, address societal issues previously considered very difficult or impossible to address, and explicitly evaluate tradeoffs (Ledford 2015).

Structured and adaptable approaches to EBM are being developed at institutions across the globe (e.g., Lynch et al. 2015, West et al. 2014). In the United States, the principal federal agency tasked with managing coastal and marine ecosystems is the National Oceanic and Atmospheric Administration (NOAA). NOAA's vision is to create "healthy ecosystems, communities and economies that are resilient in the face of change" (NOAA 2010). Historically, different parts of NOAA worked independently, meeting single-sector mandates related to weather, climate, fisheries, spatial planning, and coastal resilience. But even some of the most straightforward of NOAA's mandates are mired in complexity and require a more holistic approach. For example, determining stock status and ending overfishing has been the primary mandate of the National Marine Fisheries Service (NMFS) since the Magnuson-Stevens Fisheries Conservation and Management Act (MSA) was reauthorized in 1996; yet, this task has proven to be challenging (Murawski 2010). The effective rebuilding of depleted fish stocks involves complex social-ecological relationships (Khan and Neis 2010). Additional complexities include climate change and social, cultural, and economic reliance on fishing (Clay and Olson 2008, Himes-Cornell and Kasperski 2016, Holsman et al. 2017, Wilson et al. 2018).

To address these complexities and develop adaptable and more comprehensive science, NOAA recognized that new approaches were needed. The new approaches had to build trust and meaningful relationships with partners and stakeholders (Crandall et al. 2019), mitigate known and unforeseen threats (Maas-Hebner et al. 2016, Pinsky and Mantua 2014), adjust to unpredictable feedbacks (Shultz, Zuckerman, and Suski 2016), and prevent stovepiped decision-making such that tradeoffs are explicitly evaluated and results are transparent (DeFries and Nagendra 2017). To that end, ten years ago NOAA adopted the Integrated Ecosystem Assessment (IEA) approach. It was as a "call to action" for researchers and silo-ed management agencies to rise to the challenge of providing effective science support for EBM (Harvey et al. this issue). The IEA approach (Figure 1; Levin et al. 2009) provides an adaptable framework for scientists to work with stakeholders and partners to consider all interactions within an ecosystem (Figure 2), including humans, and develop the science to support EBM. The IEA approach includes scoping to define the goals and system, development of indicators to assess the status of the ecosystem, conducting a risk assessment to prioritize efforts, evaluating management strategies, and monitoring to reevaluate goals and the overall system. The details of the IEA approach are described by Monaco et al. (this issue). The architects of the NOAA IEA concept and program stated the IEA approach was meant to help draw meaningful and lasting connections to end-users. In Harvey et al. this issue, Fogarty states "The science is superb but if it's going to make the translation into implementation, it's got to have a real customer that's interested in a product, is going to support it in legislative and budgetary processes, and use it."

The goal of this paper is to demonstrate, through a series of case studies, how scientists, stakeholders, and managers built trust and meaningful relationships over the last ten years that fostered the development of science and tools which are addressing complex ecosystem challenges. The variety of partners, scales, and ecosystem considerations highlighted in these five case studies from regions across the U.S. (Figure 3) showcase how NOAA's IEA approach is adaptable and supporting progress toward NOAA's vision of healthy and resilient ecosystems, communities, and economies.

IEA case studies

Linking the marine ecosystem with community well-being in Sitka, Alaska

Sitka, Alaska is a fishing community located on the west coast of Baranof Island in the Gulf of Alaska (GOA) (Figure 4). It is one of the 10 largest ports in the U.S. based

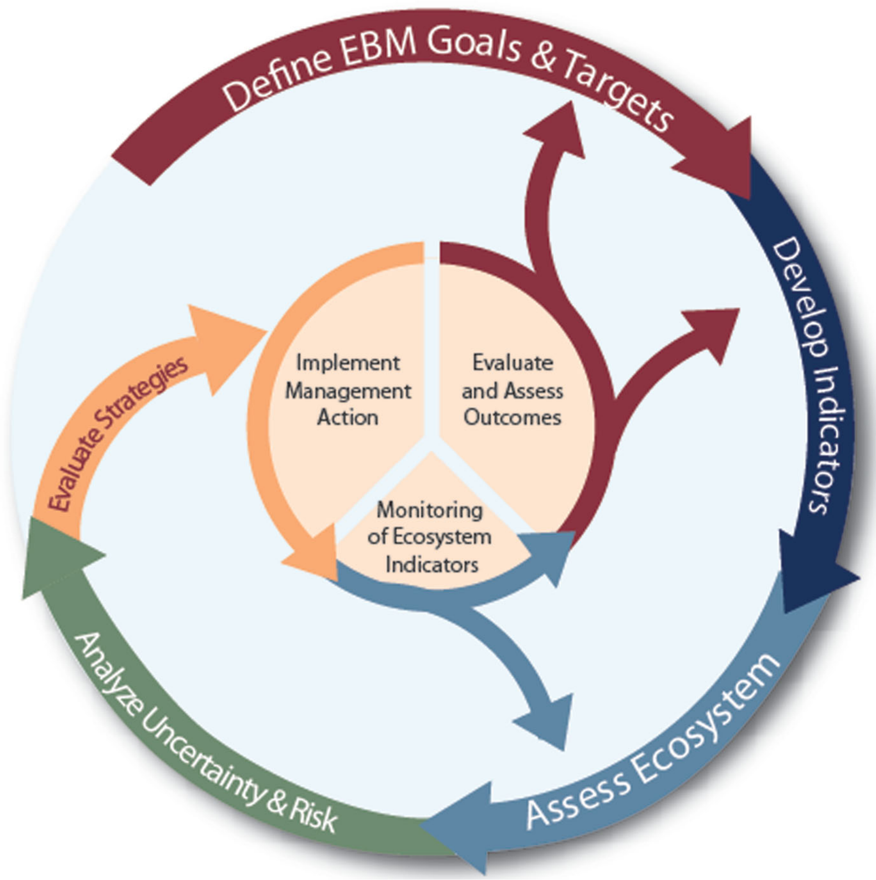

Figure 1. The NOAA Integrated Ecosystem Assessment Approach. Credit: Levin et al. 2009.

upon the value of seafood landings (NMFS 2018a). Sitka has experienced environmental changes within its local marine ecosystem (Sitka Sound). Decadal-scale climate regime shifts have produced sudden taxonomic reorganizations (Litzow 2006) while intra-decadal climate shifts such as marine heatwaves affect the distribution, recruitment, and abundance of many marine populations (Peterson, Bond, and Robert 2016). These biophysical changes propagate to Sitka residents' social, economic, and ecological well-being. For example, aspects of residents' well-being such as income, job, and food security are challenged when there are changes in important commercial, subsistence, and recreational fish species' abundance and distribution (Rosellon-Druker et al. 2019).

NOAA has a robust history addressing challenges to fisheries, such as climate change (Colburn et al. 2016). However, linking human, biological, and environmental components has been challenging. Building healthy resilient ecosystems, communities, and economies in Sitka requires scientists, partners, and stakeholders to build trust and meaningful relationships to more comprehensively incorporate human dimensions and several ecosystem components into management process (Liu et al. 2007). Scientists from NOAA's Alaska Fisheries Science Center (AFSC), and the University of Alaska Fairbanks (UAF) used the IEA approach to collaborate with stakeholders. This created a better understanding of the linkages between the community and the marine ecosystem

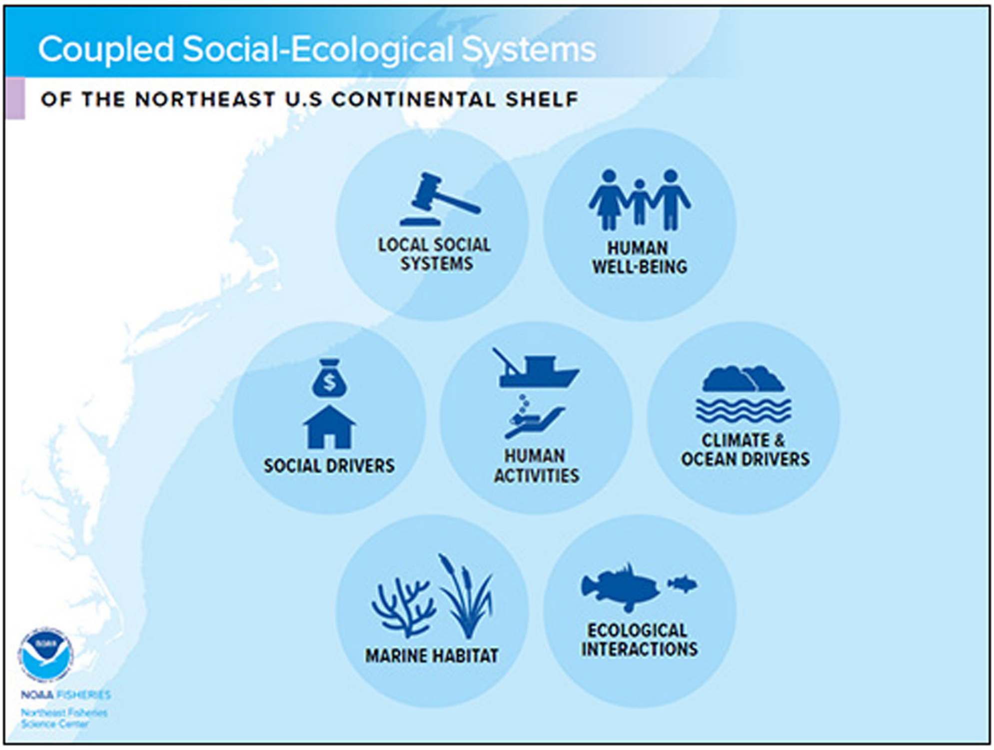

Figure 2. Ecosystem components of the Northeast Continental Shelf, as an illustrative example of the social and ecological linkages and complexities in a marine ecosystem. Credit: Northeast Fisheries Science Center.

to evaluate how perturbations in the local ecosystem can affect the community and local economy in Sitka. They focused on the development of conceptual models for four focal fisheries of Southeast Alaska (Pacific halibut (*Hippoglossus stenolepis*), Chinook salmon (*Oncorhynchus tshawytscha*), sablefish (*Anoplopoma fimbria*) and Pacific herring (*Clupea pallasii*)) that linked biological, environmental and social aspects of the local ecosystem (e.g., Figure 4). (Rosellon-Druker et al. 2019).

Conceptual models represent an essential part of the first stage of the IEA loop (Figure 1). These models were co-produced between scientists and community members and resource stakeholders in Sitka, including subsistence and commercial use harvesters, harvester representatives and fishery managers, community health and well-being educators, Alaska Natives and tribal employees, and local scientists (Rosellon-Druker et al. 2019). First, relevant scientific publications that identify key physical, social, economic, and biological components and their connections were compiled and synthesized to construct preliminary scientific-based conceptual models. Second, during workshops held in April and November 2018, Sitka community members refined these initial conceptual models by adding missing components or correcting linkages (Rosellon-Druker et al. 2019). Due to resident feedback, local river systems, the Sitka eddy, and other components were added to the model (Rosellon-Druker et al. 2019). Workshop participants also identified factors affecting resident participation in these fisheries and impacts of changing conditions on residents' capacity to derive well-being, such as job

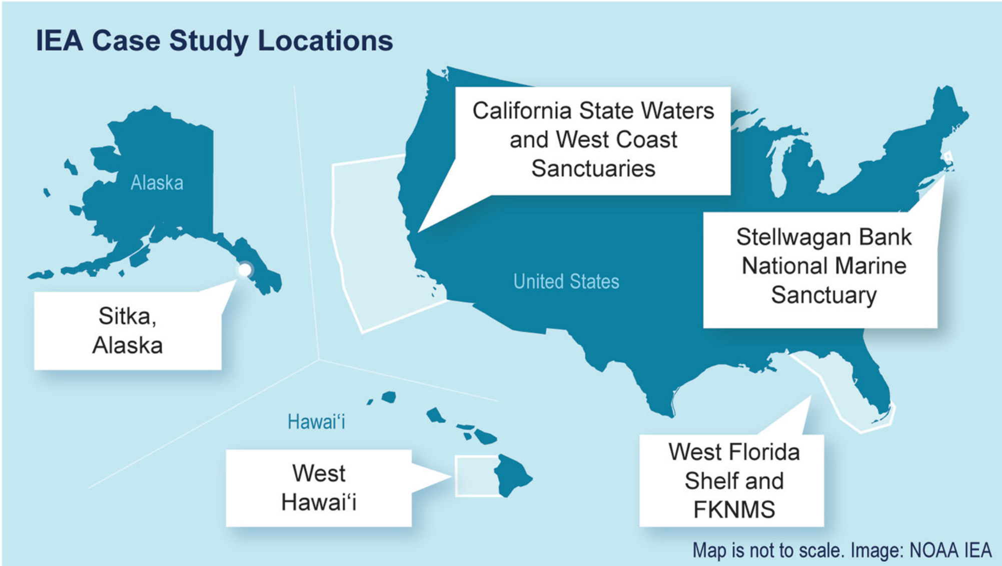

Figure 3. Location of case studies presented in this paper. Credit: NMFS Office of Science and Technology/Ellen Spooner and Jacqui Fenner.

security, sense of place, and identity, from fishery resources. Indicators to track these impacts, inform management actions, and eventually allow the community to better adapt to changing conditions were also identified (Szymkowiak & Kasperski this issue).

Integrating western scientific information with local ecological knowledge (LEK) into co-produced conceptual models allowed for linking human well-being (jobs, sense of place, etc.) with biological and environmental components of a social-ecological system, which was previously challenging. It also built trust and a meaningful relationship with the community because the communities were able to see how their recommendations changed the initial models (Rosellon-Druker et al. 2019). Building this trust is important because when the models are used to predict future scenarios, the community is more likely to trust the results of the model and act accordingly (Crandall et al. 2019). For example, LEK helped scientists to identify that the increase of squid populations in or near Sitka Sound in recent years might be an important ecological scenario explaining the dynamics of focal fisheries. Concomitantly, this collaborative effort resulted in the identification of knowledge gaps related to the biology and ecology of the focal species that may potentially guide or strengthen new or current research lines (Rosellon-Druker et al. 2020 manuscript submitted).

Information developed from this project is intended for integration into fisheries management processes in the North Pacific Fishery Management Council as part of the already existing structure developed through Ecosystem Status Reports being presented to the Gulf of Alaska Groundfish planning team and others (Rosellon-Druker et al. 2019). The trust and meaningful relationships built in this process will help scientists and communities better communicate and therefore adapt when future scenarios arise, making the science process and eventually the communities more resilient. The development of more comprehensive ecosystem models will allow for more accurate predictions of how the social-ecological system will react to future perturbations.

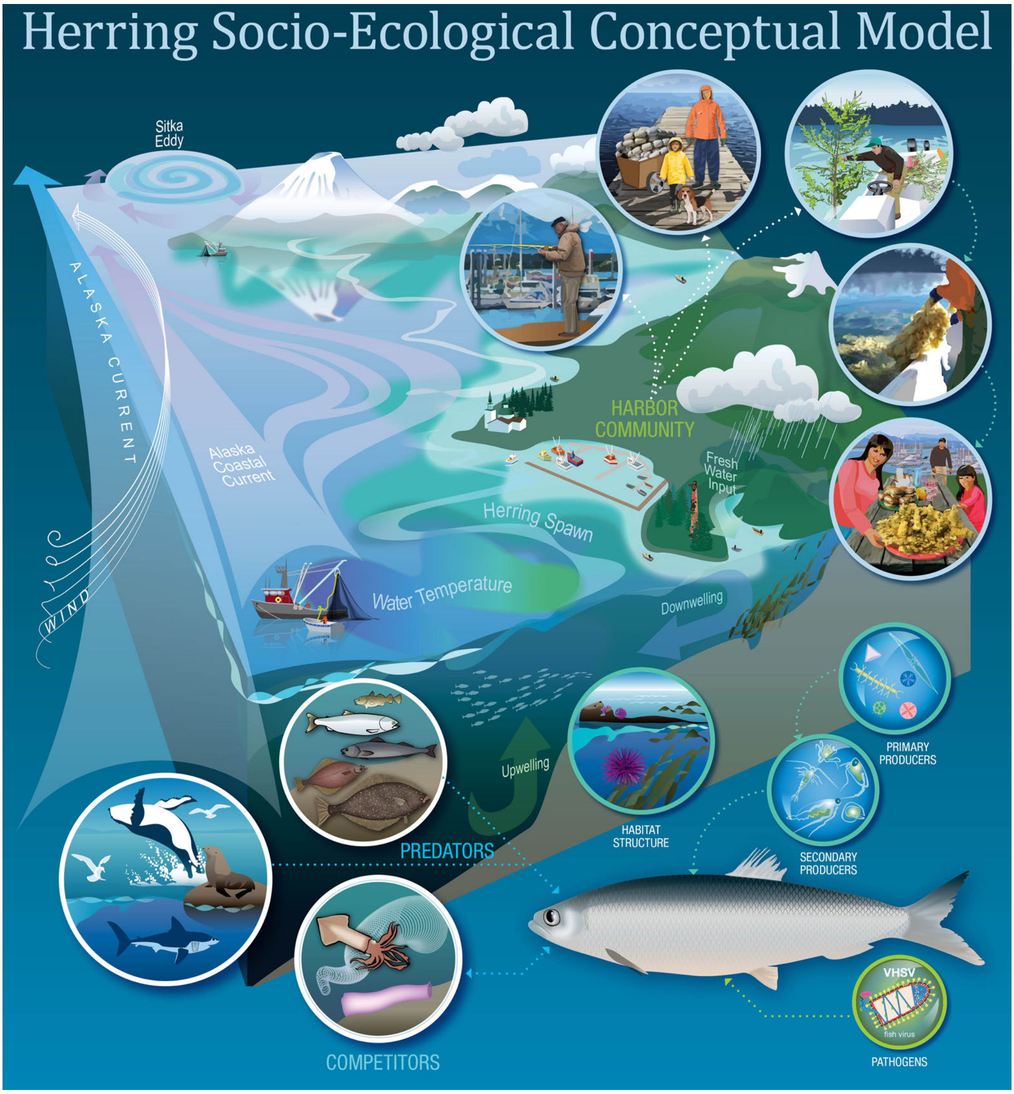

Figure 4. Conceptual model of the herring fishery in the Sitka Sound Marine Ecosystem. NOAA scientists and Sitka community members identified key components within and linkages among environmental, biological, and social components of the herring fishery within the community of Sitka, Alaska. Credit: Alaska Fisheries Science Center/Rebecca White.

Responding to red tide impacts on communities in Florida

Harmful algal blooms are increasing around the globe and have serious impacts on fisheries, coastal economies, and human health (Larkin and Adams 2007). In the Gulf of Mexico, the most common harmful algal blooms are "red tides" caused by the dinoflagellate *Karenia brevis*. These blooms have been documented for hundreds of years (Magaña, Contreras, and Villareal 2003, Steidinger 2009). Severe and prolonged red tide bloom events occur intermittently on the West Florida Shelf (Stumpf et al. 2008), however, there is much uncertainty regarding the specific factors leading to red tide bloom development and persistence (Heil et al. 2014).

A major bloom in 2005 spurred awareness of the impacts of red tide on economically important grouper species, and prompted action to incorporate the related mortality effects into fishery stock assessments (SEDAR (Southeast Data, Assessment, and Review)) 2006a, 2006b). Research was conducted to estimate the impacts of red tide blooms on individual fish populations (Sagarese et al. 2015, Walter et al. 2013), as well as in a multi-species context (Grüss et al. 2016). This included evaluating management strategies to provide guidance on how fishery managers could increase the resilience of stocks affected by episodic mass mortality events from red tide (Harford et al. 2018). The research to quantify impacts of red tide on fish populations resulted in more accurate stock assessments, improved catch advice, and management guidance to address uncertainty associated with future red tide events.

Unfortunately, while assessment and management of grouper stocks has been made more robust, the region has continued to endure frequent severe red tide blooms in recent years and as of 2018 the red grouper (*Epinephelus morio*) population was estimated to have dropped to an all-time low (SEDAR (Southeast Data, Assessment, and Review) 2019). In 2018, NMFS biologists and social scientists led a participatory group conceptual model-building initiative, which provided an understanding of how the social-ecological system was impacted by severe red tide blooms (Figure 5). Insights were gained on both the complex biological impacts of red tide and how red tide affects the resilience of fishing communities. For example, fishermen described instances of red tide being associated with hypoxia and benthic mortality, which has only been documented in rare cases in the literature (e.g., Driggers et al. 2016). Furthermore, red tides impact other aspects of the system, such as aquaculture activities, private recreational fishing, tourism, local seafood markets, and real estate values (Backer 2009). Ongoing research regarding these additive and potentially synergistic effects suggests that the most recent red tide bloom affected the resilience of communities to an extent that had not occurred in recent history (Karnauskas et al. 2019). Therefore, maintaining healthy and resilient fishing communities requires not only maintaining accurate stock assessments and solid management advice in the face of environmental stressors, but also an understanding of social and economic impacts of these events so that scientific advances can help fishing communities adapt.

Weekly forecasts of red tide blooms have been developed to minimize societal impacts due to respiratory health issues (Berdalet et al. 2016) and to assist safe shellfish harvest (Heil and Steidinger 2009), but improved seasonal forecasts could assist fishermen and other coastal industries with business-planning decisions and potentially increase their resilience to prolonged blooms. Improved understanding and management of red tide blooms in this region has been impeded by a lack of regular monitoring of the algal species *K. brevis* and the physical conditions that favor initiation of the blooms (Heil et al. 2014, Weisberg et al. 2019). One advantage of the participatory methods employed with the IEA approach is that it allows for co-production of knowledge and enables scientists and stakeholders to identify common gaps in understanding. In this case, a new citizen-based monitoring effort was established; fishermen are now working with state and federal agencies to monitor offshore waters and provide data for improved forecasting (www.floridawatermen.org). These new data will lead to an improved understanding of red tide blooms and improved monitoring, which should

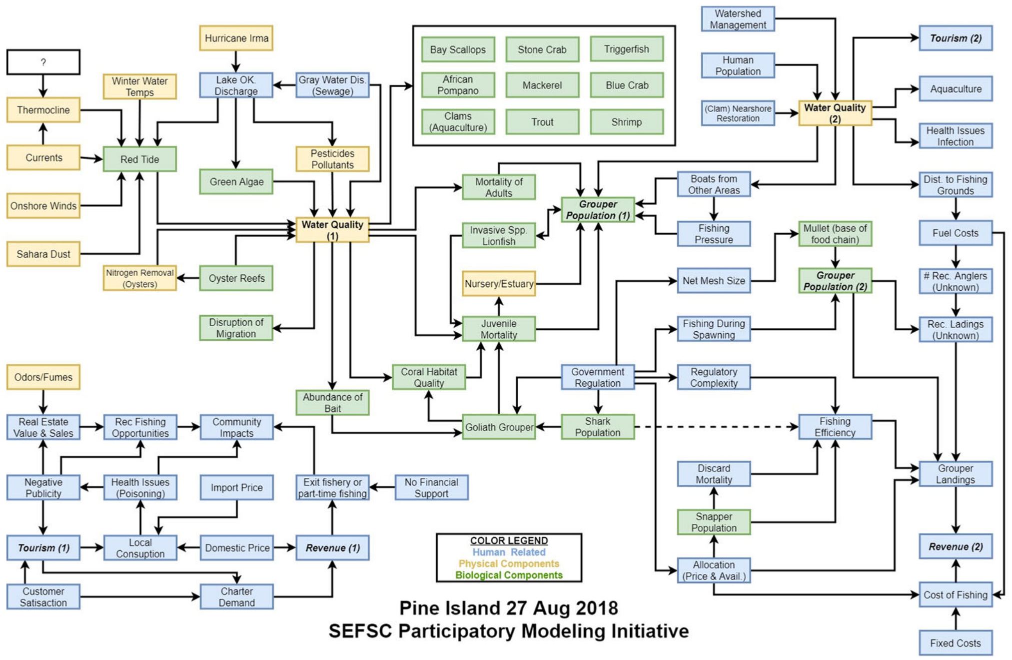

Figure 5. Conceptual model of all the components and linkages of fisheries on the west Florida Shelf built by NOAA fishery biologists and social scientists in a participatory group conceptual model-building initiative. Blue boxes are human related, yellow boxes are physical components, and green are biological components. Credit: Southeast Fisheries Science Center/Mandy Karnauskas.

benefit not only the fishing industry, but other coastal community groups in maintaining resilience in the face of a major regional stressor.

An ecological risk assessment of important California fisheries

Fisheries are an important part of California's economy, culture, and history (Pomeroy, Thomson, and Stevens 2010). Commercial fishery landings are worth millions of dollars per year and California's seafood industry supports thousands of jobs (NMFS 2018a). Yet, these important fisheries can potentially cause fish populations to decline, damage important habitat for marine life, or lead to the capture of non-target species, threatening the structure and function of the ecosystem. Effectively addressing all potential impacts requires an approach that evaluates multiple pressures on multiple ecosystem components (Holsman et al. 2017).

The California Department of Fish and Wildlife (CDFW) is the state agency charged with "ensuring the conservation, restoration, and sustainable use of California's living marine resources" (CDFW 2018) via the Marine Life Management Act (MLMA). The CDFW's Master Plan (2001) guides the implementation of California's MLMA by assessing the vulnerability of specific stocks to fishing, developing Fishery Management Plans, engaging the public, and collecting data (CDFW 2001). However, other objectives related to the potential impacts of fisheries to habitat, bycatch and others are not fully addressed. Maintaining healthy and resilient ecosystems and communities requires not only maintaining sustainable target species populations, but also building trust and meaningful relationships with stakeholders so that management and fishing communities can work together to understand fisheries impacts on bycatch and habitat and adapt to changing environments.

In 2015, the CDFW began to update its MLMA Master Plan and attempted to address fisheries' potential impacts to habitat and bycatch. The challenge was to create a systematic, efficient, and transparent approach to prioritize fisheries for additional management plans. The California Ocean Science Trust, CDFW fishery managers, and NOAA scientists collaborated with stakeholders to pilot an ecological risk assessment (ERA), adapted from the IEA approach, that evaluated the potential impacts of nine California state-managed fisheries on target species, habitat, and bycatch (Figure 6) (Ramanujam et al. 2017, Samhouri et al. 2019). Risk was evaluated based on exposure and sensitivity. More exposed and sensitive ecosystem components (target species, bycatch groups, habitat groups) were considered to be at higher risk.

To ensure transparency and build meaningful relationships with stakeholders, workshops were conducted in 2018 to solicit feedback on the proposed ecological risk assessment (Samhouri et al. 2019). Stakeholders included fishermen that participated in the nine commercial and recreational fisheries assessed, environmental non-governmental organizations, state managers, and other federal fisheries experts. At the workshop scientists presented the proposed approach and asked stakeholders for feedback. A challenge that arose was addressing the personal and professional biases of the project team and workshop participants. Parts of the risk assessment that were changed or established based on feedback during the workshop included identification of experts to conduct scoring assessments; selection of target species and bycatch and habitat groups; and definitions of exposure and sensitivity attributes.

The adaptation of the risk assessment through engagement with stakeholders fostered the inclusion of multiple perspectives and interpretations of existing data and risk evaluations, setting the stage for broad stakeholder buy-in and therefore its application in management. The more holistic evaluation of risk imposed by a fishery to target species, bycatch species, and habitats, rather than solely to individual target species, is expected to foster fisheries management decisions that maintain key ecosystem functioning and vibrant fisheries (Samhouri et al. 2019).

A modified ecological risk assessment, built from the IEA approach, was agreed upon and is being used as the basis for CDFW to prioritize its fisheries management activity in their updated Master Plan for the MLMA (Figure 6). This example demonstrates how the IEA approach can inform on-the-ground policy and management. While specific changes in management practices are yet to be seen, the participatory process is expected to foster increased trust in future assessments and their use for management, which is a key goal of the IEA approach as stated in Harvey et al. (this issue) and allows for management and stakeholders to better adapt to future scenarios. Furthermore, the transparency and comprehensiveness of the ecological risk assessment developed by the project team allows managers to better prioritize efforts and resources on fisheries with greater impacts to key target species, bycatch species, and habitats, while maintaining key ecosystem functions.

This pilot ecological risk assessment was possible, in part, because the Ocean Science Trust gained trust in the IEA approach from previous efforts within the IEA program

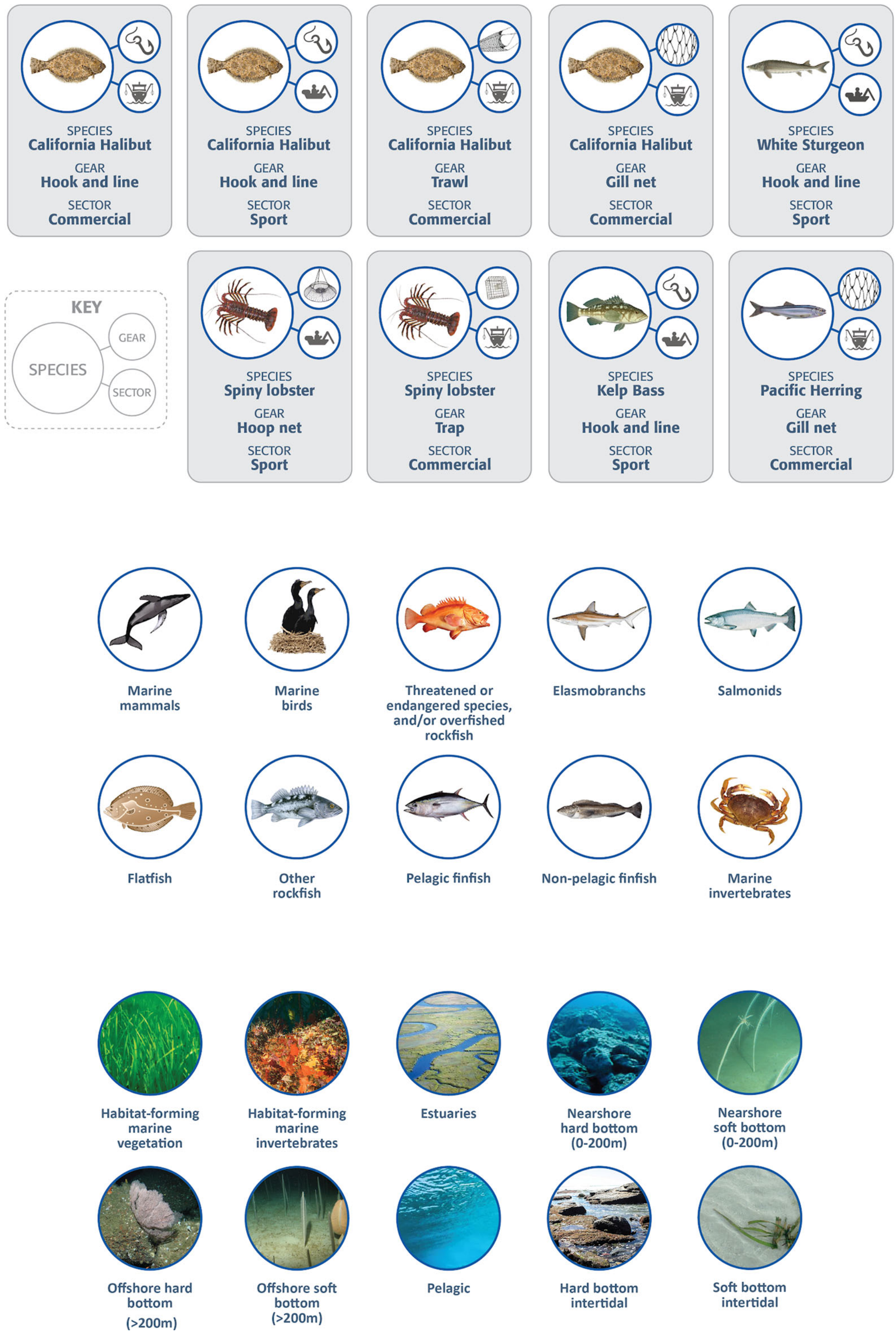

Figure 6. Nine California fisheries (units of analysis represent a species, gear type, & sector combination), bycatch species, and habitat type selected for the pilot risk analysis. Credit: California Ocean Science Trust/Hayley Carter.

in the Puget Sound (Washington state, USA) to develop a framework to evaluate ecosystem risk in sub-regions of the California Current (Samhouri and Levin 2012). As these IEA-end-user relationships have grown, issue-based scoping has become easier and better able to adapt to different challenges. As in this case study, scientists, managers, and stakeholders collaborated to refine this risk assessment to better meet the objectives of the updated MLMA Master plan. These relationships and adaptability of the approach makes the science and management process more resilient in the face of this complex social-ecological challenge, and underscores the value of boundary-spanning organizations (Bednarek et al. 2016) like OST in bridging ecosystem science and policy.

Evaluating the vulnerability of West Hawai'i coral reef ecosystems to climate change and human impacts

The west coast of the Big Island of Hawai'i (West Hawai'i) is home to a diverse array of corals, fish, and marine mammals and nearly a quarter of Hawai'i's reef-associated species are endemic to the Hawai'ian Islands (Kay and Palumbi 1987, Jokiel 1987, Randall 1998). In addition to hosting considerable biodiversity, coral reef ecosystems in West Hawai'i are critically important to the local economy, history, culture, and environment (Kaiser, Krause, and Roumasset 1999). The region's coral reefs provide a number of ecosystem services, including a thriving tourism industry that supports jobs and income, shoreline protection against storms and waves, and significant species that are used for recreational, subsistence, and commercial fishing, as well as for cultural practices (Gove et al. 2019).

Coastal development, wastewater pollution, sedimentation, invasive species, fishing pressure, and the effects of climate change are threatening these marine ecosystem services (Gove et al. 2019). These issues threaten not only the stability of the marine environment, but also the communities that rely on that environment. Maintaining healthy and resilient ecosystems, communities, and economies in West Hawai'i necessitates that natural resource managers and community members build trust and meaningful relationships to use an approach that simultaneously evaluates threats to the ecological, social, and economic components of the ecosystem.

Galvanized by the new Marine 30 × 30 Initiative from the State of Hawai'i, scientists, community members, and state and federal managers are now collaborating to address these issues. The 30 × 30 initiative aims to "effectively manage 30% of Hawai'i's nearshore waters by 2030" (DAR 2019). This initiative builds upon Hawai'i's rich and effective traditional management practices. In collaboration with NOAA's West Hawai'i Habitat Focus Area team, The Nature Conservancy, State managers, and community members, NOAA scientists have adapted NOAA's IEA approach to increase research capacity, prioritize management efforts, and build resilient reefs, communities, and economies in West Hawai'i (Maynard et al. 2019). In order to prioritize management efforts, scientists conducted a risk assessment of the vulnerability of West Hawai'i's coral reef ecosystems to climate change (Maynard et al. 2019). The analysis revealed important differences in ecosystem vulnerability to climate change in the region, indicating that ecosystem services such as coastal protection, recreation, tourism, and food resources in coastal communities will be impacted, sometimes severely. Reefs that are less vulnerable to climate change are projected to experience annual severe bleaching 10 years later than high vulnerability reefs. Most severe impacts from reef fish fishing, sedimentation, and tourism are near the city of Kailua-Kona. This suggests a strong connection between population density and the severity of human impacts on coral reefs (Maynard et al. 2019).

Social scientists have also adapted the IEA approach to work with communities in West Hawai'i and better understand the links between ecosystem services and human well-being. Human well-being includes non-material benefits and values to communities such as cultural connections to a place. These human well-being indicators are helping to improve representation of human well-being and cultural importance in management of these social-ecological systems (Leong et al. 2019).

The result of this partnership has been the creation of a unique government-environmental organization-community exchange that provides an effective mechanism to share information and ideas, develop strategies to tackle challenges, and ensure community ownership and participation (NMFS 2016b). The collaboration has empowered the State's efforts by bringing science, government, and community into a trusted alignment. Together they are targeting highly vulnerable areas in West Hawai'i to reduce land-based pollution, increase ecosystem resilience to climate change, amplify community engagement, and coordinate numerous restoration, research, and monitoring activities. By adapting the IEA approach to build relationships, evaluate coral reef vulnerability, and incorporate human well-being into management processes the ecosystem, community, and economy of West Hawai'i is better positioned to adapt to the challenges of climate change, reef fish fishing, sedimentation, tourism, and others.

Tracking the health of marine ecosystems in National Marine Sanctuaries

NOAA's Office of National Marine Sanctuaries (ONMS) manages 15 protected areas encompassing more than 1,500,000 square kilometers of marine and Great Lakes waters. Sanctuaries face many complex stressors such as climate change and the need to balance societal demands including recreational fishing and tourism with maintaining sustainable ecosystems. Governance for each is supported by management plans, condition reports, research, monitoring, education, resource protection and enforcement programs, and stakeholder engagement.

Sanctuary management relies heavily on input from stakeholder-based sanctuary advisory councils, partner agencies, and the general public (ONMS 2019a). Sanctuary condition reports, which help managers prioritize management plan activities, rely on expert scientific opinion to rate the status and trends of resources and pressures within the sanctuaries. Feedback from early reports (e.g., ONMS 2008, 2009) asked for more quantifiable metrics and clear communication on levels of uncertainty/confidence (e.g., ONMS 2019b).

Concurrently, the NOAA IEA program was developing, and it became clear that the framework was particularly well suited to support ONMS. Both use collaborative, interdisciplinary science to explicitly consider many linkages in an ecosystem, including humans, and inform decision-making. ONMS partnered with the IEA Program to improve condition reports by using the IEA approach to select and assess the status and trends of quantitative and scientifically rigorous indicators. These indicators answer a set of standardized questions within sanctuary condition reports (Brown et al. 2019, Montenero, *pers. comm*. 2019).

The ONMS/IEA collaboration is expanding, but has already supported condition report and management plan development for many sanctuaries. The California Current IEA (CCIEA) team partnered with Monterey Bay, Channel Islands, and Olympic Coast sanctuaries to update their condition reports (Brown et al. 2019, ONMS 2015, ONMS 2019b, Williams et al. this issue). Quantitative indicators were identified and used to rate the quality of water, habitat, living resources, and heritage resources in the sanctuaries, as well as the ecosystem services they provide. At Monterey Bay NMS, IEA staff created conceptual models for eight major habitats and aggregated key indicators for each (Brown et al. 2019). These were drawn from the indicator portfolio developed by the CCIEA, local researchers, long-term monitoring datasets, and other West Coast ecosystem status reports. The habitat-specific suites of indicators were presented to experts for consideration in rating resource conditions. Similar approaches were taken in the two other sanctuaries, supported also by NOAA's National Centers for Coastal Ocean Science.

Similarly, Northeast IEA staff partnered with Stellwagen Bank NMS and the Gulf of Mexico IEA team partnered with Florida Keys National Marine Sanctuary (FKNMS) to adapt and downscale IEA data and products to evaluate quantitative metrics for each sanctuary's condition report (Pittman 2019, Montenero, *pers. comm.* 2019) and other regional priorities (e.g., FKNMS's Restoration Blueprint). For Stellwagen Bank, data on the condition of relevant resources and human activities were synthesized from the State of the Ecosystem Report for the Northeast Shelf Large Marine Ecosystem (Pittman 2019). In the Florida Keys, the IEA team, ONMS staff, and interdisciplinary experts worked together to identify natural resource and human use indicators to track and predict changes in the sanctuary under different management scenarios.

By adapting the IEA approach to build trust and a mutually beneficial collaboration, sanctuaries stakeholders and managers are more likely to rely and eventually act on the data being provided. The development of quantitative indicators that track human activities and the quality of water, habitat, living resources, and heritage resources allows experts and managers to quantify and target high impact stressors and support development of more resilient sanctuaries. For example, experts are able to quantitatively track how visitors in sanctuaries like the Florida Keys, Channel Islands, and Stellwagen Bank patronize diving, whale watching, cruise ships, and fishing operators. These are important human activities to the local economy but also impact the ecosystem. Quantifying those impacts allows managers to balance tradeoffs and assess how well the sanctuaries are able to sustain these economic drivers against growing stressors. Therefore, the integration of the IEA approach in marine sanctuaries advances the sanctuaries' ability to balance use and protection. This balance creates communities, ecosystems, and economies that can adapt to stressors and become more resilient, aligning with NOAA's vision (Brown et al. 2019, ONMS 2019b, Pittman 2019, Williams et al. this issue).

Discussion

The IEA approach evolved over the last decade from a concept to an implemented framework integrating a broad spectrum of scientific disciplines, including biological, physical, social and economic, into management decisions. Crucial to this success was the communication, trust, and meaningful connections that scientists built with stakeholders, partners, and managers (Brown et al. 2019, Karnauskas et al. 2019, Maynard et al. 2019, Rosellon-Druker et al. 2019, Samhouri et al. 2019). While not all partnerships built with the IEA approach are described here, these five case studies highlight the diversity of partners and stakeholders using the IEA approach. In particular, IEA's collaborative development of conceptual models allow for the effective and non-confrontational communication between interdisciplinary scientists, managers, and stakeholders (Brown et al. 2019, Rosellon-Druker et al. 2019). This enhanced communication, creates more management buy-in which is typically associated with improved management outcomes (Crandall et al. 2019). For example, along the west coast of Florida, scientists from various disciplines are using the IEA approach to engage with fishermen. This has resulted in a new citizen-based monitoring effort. This will help scientists, managers, and stakeholders better understand and predict red tides and their impact to the community's well-being. The adoption of an adapted ecological risk assessment into management as a result of enhanced communication was also seen with the California Department of Fish and Wildlife MLMA updated Master Plan (Samhouri et al. 2019). The IEA approach is also now a standard practice to update condition reports in sanctuaries (Brown et al. 2019). These relationships continue to grow and position scientists, managers, and stakeholders to further improve communication and better address rapidly evolving and future issues.

Over the past decade the IEA approach has also improved collaboration among social and ecological scientists inside and outside of NOAA. This collaboration has led to the integration of different information (Brown et al. 2019, Karnauskas et al. 2019, Maynard et al. 2019, Rosellon-Druker et al. 2019, Samhouri et al. 2019). It is often overwhelming to address the many complex issues facing marine ecosystems, because doing so effectively requires the integration of large amounts of information across multiple disciplines. In each case study presented here, the IEA process provided a framework to integrate complex information (e.g., biophysical and social components of the ecosystem). This allowed for a more complete understanding of how changing marine ecosystems impact not only ecological but also human components (Marshall et al. 2018). For example, scientists in the Sitka case study connected community well-being with species distributions (Rosellon-Druker et al. 2019). This linkage will also help scientists predict how stressors will affect community well-being (Szymkowiak and Kasperski this issue). Scientists in West Hawai'i developed a better understanding of links between ecosystem services including cultural ecosystem services among other human well-being indicators (Leong et al. 2019). These linkages can now be better represented the unique government-environmental organization-community partnership that developed. This holistic insight broadened the scope of and helped prioritize management concerns in these regions.

The IEA approach was never meant to be a prescriptive set of directives (Harvey et al. this issue). These case studies describe how scientists, stakeholders, and managers adapted the IEA approach to meet ecosystem goals at various geographic scales and levels of management (community, state, federal, etc.). For example, several National Marine Sanctuaries have modified the indicator evaluation methods and results of nearby IEA programs to more efficiently downscale the information to the boundaries of the sanctuary. This has increased sanctuaries' ability to measure components in the face of change (Brown et al. 2019, Pittman 2019, Montenero, *pers. comm.* 2019). The IEA approach has also been adapted to international efforts as well, such as the multinational network under the International Council for the Exploration of the Sea (ICES) Science Steering Group on Integrated Ecosystem Assessments (SSGIEA) (Walther and Möllmann 2014) and the ICES Working Group on the Northwest Atlantic Regional Sea (WGNARS). This effort developed an IEA for the Northeastern U.S. and Atlantic Canada and was built upon expertise from NOAA's IEA program and several other science institutions (DePiper et al. 2017). The IEA approach is helping to build resilient ecosystems, communities, and economies across the globe.

Conclusion

Over the past decade, the NOAA IEA approach has built trust and meaningful relationships between a variety of different scientists, managers, and stakeholders; improved collaboration among social and ecological scientists; aided the linkage of social and ecological components together; and adapted to a variety of different geographic scales and management needs. Meaningful relationships, collaboration among interdisciplinary scientists, linking various ecosystem components together, and being adaptable are all key pieces to addressing complex challenges and building more resilient ecosystems, communities, and economies. Therefore, the IEA approach can help NOAA and other management entities make progress toward more resilient ecosystems, communities, and economies.

There are many opportunities for growth in the use of the IEA approach in the next ten years. This is evident in the increasing demand for IEAs across international organizations, national marine sanctuaries, fishery management councils, state agencies, and within local communities. There is also a need to better incorporate other ocean sectors and agencies with mandates within coastal and marine ecosystems to achieve full EBM. NOAA scientists will continue to partner with managers, stakeholders, and other scientists to adapt NOAA's IEA approach to the needs of ecosystems, communities, and economies to advance EBM and build resilient ecosystems, communities, and economies.

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