Journal of Applied Ecology

Journal of Applied Ecology 2016 doi: 10.1111/1365-2664.12633

PRACTITIONER'S PERSPECTIVE

Ecosystem monitoring for ecosystem-based management: using a polycentric approach to balance information trade-offs

Adel Heenan[1,2]*, Kelvin Gorospe[1,2], Ivor Williams[2], Arielle Levine[3,4], Paulo Maurin[4], Marc Nadon[1,2], Thomas Oliver[1,2], John Rooney[1,2†], Molly Timmers[1,2], Supin Wongbusarakum[1,2] and Russell Brainard[2]

[1]*Joint Institute for Marine and Atmospheric Research, University of Hawai'i, Mānoa, Honolulu, HI 96822, USA;* [2]*NOAA Pacific Islands Fisheries Science Center, National Marine Fisheries Service, Honolulu, HI 96818, USA;* [3]*Department of Geography, San Diego State University, San Diego, CA 92182, USA; and* [4]*NOAA Coral Reef Conservation Program (The Baldwin Group Inc.), Silver Spring, MD 20910, USA*

Key-words: conservation, ecosystem approach, ecosystem-based fisheries management, fisheries assessment, long-term ecosystem monitoring

Introduction

Over the past few decades, the call for ecosystem-based management (EBM) created a major shift in global resource management policy. EBM aims to achieve conservation, sustainable use and the fair allocation of benefits from natural resources, thereby striking a balance between short-term needs and sustainability (Cowan *et al.* 2012). Monitoring in this context requires whole ecosystem indicators, including information on the status/trends of species, habitats and environmental conditions in the biophysical, and related human system.

Typically, trade-offs are implicit in ecosystem monitoring, first, because of insufficient resources to monitor all relevant biological, chemical, human and physical parameters in an ecosystem and secondly because monitoring programmes frequently have multiple, interacting goals. Hence, monitoring often focuses on only a subset of priority indicators, selected based on considerations such as (i) their suitability for assessing policy and management interventions, (ii) uncertainty over the relative importance of different processes within the ecosystem and (iii) value-laden judgements over indicator relevance to current societal objectives and priorities, given the practical and logistical resources available. Consequently, determining the appropriate spatial and temporal scales to monitor multiple indicators in complex systems is, in itself, scientifically and geopolitically complex. Ecosystem-based management involves balancing ecological scales, which are structured scientifically and driven by interacting physical, chemical and biological processes, with management scales, which are defined geopolitically and driven by governing structures and mandates. To date, the implications and trade-offs in interdisciplinary monitoring, at ecosystem appropriate scales, have received little attention.

Here, we present our experience of long-term ecosystem monitoring, from establishing and implementing the interdisciplinary Pacific Reef Assessment and Monitoring Program (Pacific RAMP), the Pacific component of the US National Oceanic and Atmospheric Administration's (NOAA) National Coral Reef Monitoring Plan (NCRMP). We focus on the trade-offs made to maintain data integrity within a single discipline, while retaining relevance and integrating across multiple disciplines in a changing policy environment. We propose cross-scale monitoring systems as a means to effectively address trade-offs that likely will arise in ecosystem monitoring. To achieve this, we promote a polycentric approach to monitoring and outline three recommendations that could enable current monitoring practitioners to work towards attaining the information requirements for implementing ecosystem-based management.

Polycentric monitoring

Polycentricity, in governance, is viewed as critical to ecosystem-based management (Ostrom 2010). Polycentric governance is characterized by an organizational structure where multiple independent actors mutually order their relationships with one another under a general system of rules (Ostrom 1972). These multiple, nested yet independent decision-making units can operate across a range of scales, from local–regional–national–transnational. Governing units balance centralized (top-down) and decentralized (bottom-up) control, and these entities enter

*Correspondence author. E-mail: adel.heenan@gmail.com
†Deceased.

into either contractual or informal cooperative endeavours that work in a predictable and consistent manner (Ostrom, Tiebout & Warren 1961; Folke *et al*. 2005). Benefits of polycentricity include a higher level of cooperation and trust between participants, greater systems learning, innovation and adaptation for increased levels of collective effectiveness at multiple scales (Ostrom 2010). Put simply, the collective whole is greater than the sum of the individual parts.

It follows then that polycentric governing institutions engaged in ecosystem-based management might benefit by collectively striving towards polycentric monitoring, where monitoring is nested and linked across spatial, temporal, disciplinary and governance scales, to meet the information requirements needed to support an ecosystem approach. In an ecosystem monitoring context, the following features could be implemented in a polycentric monitoring system, for collectively more efficient monitoring: (i) clarity on the purpose, methods and monitoring responsibilities of each monitoring unit, (ii) transparency about the strengths and shortcomings of monitoring that occurs at each scale and (iii) strategic alignment of monitoring efforts, so that interdisciplinary and geopolitical collaborations can provide the information needed for informed ecosystem-based decision-making.

US coral reef monitoring policy rationale

Marine resource governance in the USA is geopolitically separated, with different authorities responsible for the management of Federal vs. State or Territorial (herein 'jurisdictional') waters. NOAA's Pacific RAMP is federally funded to survey coral reefs in US-affiliated waters in the Pacific (0–200-nm offshore), but most of the authority to manage the near-shore (within 3-nm) lies with jurisdictional agencies. As such, federal and local monitoring programmes often are designed for different purposes, work at different spatial scales and operate independently. Below, we outline the policy rationales for national-level coral reef monitoring and how this changed over time.

In 2000, the Coral Reef Conservation Act (CRCA) authorized the long-term monitoring of US coral reefs, and several *ad hoc* monitoring efforts were established, including Pacific RAMP. In 2010, the NOAA's Coral Reef Conservation Program unified NOAA's monitoring efforts by establishing the National Coral Reef Monitoring Plan (NCRMP) for US jurisdictional coral reef ecosystems in the Atlantic, Caribbean and Pacific. Multiple data streams are collected across biological, climatic and socio-economic domains. The reporting units and priority indicators for each discipline were decided by a working group comprising relevant NOAA scientists and federal managers. The NCRMP reflects how this particular group envisaged a national programme of greatest utility to the high-level policy statements of the CRCA and jurisdictional management agency needs, at that time given available resources.

Since 2000, the NOAA Pacific Islands Fisheries Science Center has implemented biological and climate monitoring across ~40 islands and atolls in the US-affiliated Pacific within American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Hawai'i and the Pacific Remote Islands. The Pacific RAMP data and analyses have been used in a variety of opportunistic ways with national and jurisdictional policy repercussions, including the establishment of large-scale marine protected areas, listing of coral species under the US Endangered Species Act and a prohibition on take of large fish in American Samoa.

Over time, new policies arose that directly influenced both data collection and use of those data. For example, the 2006 reauthorized Magnuson-Stevens Fisheries Conservation and Management Reauthorization Act (MSRA) – the primary US fisheries legislation – requires the establishment of annual catch limits for all management unit species, including coral reef fishes. Consequently, our data have been used to support reef fish stock assessments (Nadon *et al*. 2015), directly tying our monitoring programme to a regulatory management framework. Additionally, the 2009 Federal Ocean Acidification Research and Monitoring Act requires monitoring of ocean acidification and associated ecological impacts. The Pacific RAMP adapted to collect data directly relevant to these new policies.

The National Ocean Policy (2010) called for ecosystem-based management and for greater collaboration across scales to coordinate jurisdictional and national activities, including monitoring. Furthermore, the National Marine Fisheries Service issued a 2015 Policy Directive on 'Ecosystem-Based Fisheries Management', calling for more efficient monitoring systems, which will require integration across scientific and geopolitical or governance units. In sum, even over the relatively short 15-year life span of Pacific RAMP, the policy environment has shifted to supporting ecosystem-based management. Next, we use our experience of adapting to this shifting policy environment to demonstrate the emergent trade-offs when operationalizing ecosystem-scale monitoring.

Navigating the trade-offs of ecosystem monitoring

This discussion is framed from the perspective of one component of the Pacific RAMP team that surveys fishes. We focus on this team to clearly demonstrate how the data collected are relevant to fisheries management and marine conservation objectives – two sectors that the ecosystem approach seeks to align. We highlight examples where trade-offs were handled through sensible compromise, without affecting our core monitoring purposes. We also discuss cases where it was not possible to balance conflicting monitoring rationales within Pacific RAMP efforts, but where balance could be enabled through polycentricity. We consider these trade-offs along two axes: within a discipline and across disciplines, and in each case discuss their ecological and governance scaling drivers and impacts.

TRADE-OFFS WITHIN A DISCIPLINE: REEF FISH ASSESSMENTS

The fish component's core mandate is to provide information on coral reef fishes relevant to policy and management at national, regional and jurisdictional levels under the NCRMP. As a result, our sampling framework is optimized to report on the status and trends of four priority indicators (all herbivorous fishes, all piscivorous fishes, all fishes and parrotfishes) at the island scale and across multiple jurisdictions. Our sampling domain is hard-bottom habitat in water depths shallower than 30 m. We survey randomly distributed sites via a depth-stratified design, and our reporting units are typically island and atolls. We also provide information to support the Federal government mandate to assess target stocks and establish annual catch limits. These monitoring mandates, oriented towards national- and jurisdictional-wide information requirements, have influenced which attributes of the fish assemblage we measure and how.

We seek to maximize the number of randomly allocated sites surveyed per island during each sampling period; anything that detracts from that focus will degrade our ability to meaningfully report on the status and variability of the indicators. However, ecosystem management requires broader information than Pacific RAMP has the capacity or resources to provide. We do not survey reefs deeper than 30 m, or connected soft-bottomed habitats. While these habitats are important to some species and life stages, allocating survey effort there would reduce our ability to adequately sample in the areas we deem more critical for our core objectives. We therefore have a mismatch between ecosystem and monitoring boundaries. To address this particular disconnect, we collaborate with academic researchers to examine fish assemblages in adjacent habitats and to depths up to 100 m.

Being locked into a nationally driven sampling design aimed at reporting at a regional and jurisdictional level affords little flexibility to provide data at finer spatial scales. But this type of data is often desired to address local management needs and is a component of the information required for ecosystem-based management. We generally have too few data at specific sites to determine impacts of localized acute or chronic events, like a point source of pollution, or to assess local management intervention effectiveness, like a marine protected area. In some cases, we have overcome this scaling disconnect by securing additional funding to collect data at finer scales to address specific local management issues; however, additional resources are not always available, and this *ad hoc* approach is not a sustainable model for long-term monitoring efforts.

Localized monitoring is typically the purview of the jurisdictions. Ideally, local and national monitoring would use comparable methods, sampling designs and standard indicators, or at least have information to calibrate disparate data sets to allow for integration and co-reporting for a more complete systems view. The *status quo*, however, is that within each jurisdiction, there are multiple distinct and not readily integrated monitoring efforts, using different survey methods and designs, operating and reporting at a range of local, jurisdictional and federal levels. Data integration may not always be possible, because local and national management and monitoring have different priorities, resources and work within programmes with their own historical and/or political context. Unless there is sufficient cause to standardize or integrate survey methods and sampling designs, it is unavoidable that these data optimized for different spatial and temporal scales will remain separate.

Since our priority indicators are composite groups of reef fishes, our generalist survey method is the stationary point count (SPC), which allows us to infer the status and trends of the reef fish assemblage as a whole, by collecting representative data for non-cryptic and generally abundant taxa. Were fish diversity a priority indicator, it would be more appropriate to systematically sample cryptic fauna. However, gathering data on relatively rare, exploited or ecologically important species, such as sharks, jacks and large parrotfishes, is critical to our primary monitoring purpose. Because those tend to be infrequently recorded using our generalist survey method, we employ a supplementary method – the towed diver survey method – to obtain those data. This technique involves surveying a much larger swathe of reef habitat, ~20 000 m^2 per dive compared to the 352 m^2 surveyed in a SPC survey. Divers covering that large an area cannot record all species, but by focusing on a narrow segment of the fish assemblage, this method greatly increases the encounter rate for rare species of particular interest.

In response to the mandate for annual catch limits for coral reef fishes arising from the MSRA, information gathered during Pacific RAMP became more immediately relevant for federal fisheries management. As such, we adapted our methods to gather additional data on presence, abundance and size distribution of targeted species – specifically, we expanded the time and the area over which we would record observations of target fishes in and around the sample area. We responded to the new policy-driven data need, and improved our ability to generate size distributions for important fishery species, while maintaining continuity of the core data we collect.

Our experience of adapting to changing policy and collaborating across two traditionally disparate sectors in the wider management system has been very positive. Specifically, our monitoring group, which was rooted in conservation science and conservation funds, began integrating our data with the stock assessment group. This collaboration was enabled by the existence of our extensive Pacific RAMP data set, coupled with supporting science on the utility of fisheries-independent visual-survey data for stock assessments (Ault, Bohnsack & Mester 1998). This new use of these data led to additional political, financial and institutional support for additional reef fish surveys in regions where fisheries assessments are required. By maintaining consistency in sampling design, methodology and personnel, we are building a large data set that benefits our core national coral reef monitoring purpose and directly aligns our monitoring programme to fisheries management decision-making needs.

TRADE-OFFS ACROSS DISCIPLINARY TEAMS

The fish assemblage data are only one part of the interdisciplinary monitoring performed under the NCRMP. The sampling designs for the other biological and physical data streams diverged because what is optimal to monitor mobile fish assemblages was suboptimal or impractical for other disciplines. Information on fish–habitat associations, while not a primary monitoring objective or indicator, is an important facet of ecosystem monitoring. However, co-locating fish and benthic surveys required a degree of logistical coordination that decreased the number of replicate surveys conducted by each team separately and reduced the statistical power to address the core indicators. As a result, the fish survey protocol was revised to collect benthic photo-quadrat images that are subsequently analysed by benthic specialists. Although detailed estimates of coral diversity and demographics obtained *in situ* by benthic specialists are not possible from photo-quadrats, our current approach enables a range of co-located fish and broad benthic habitat data to be gathered with minimal cost in field time.

The climate monitoring component of Pacific RAMP, on the other hand, combines permanently moored sites with haphazard carbonate chemistry sampling to monitor key physical and biological process indicators of ocean warming and acidification. With four fixed stations per island, there is limited ability for inference at that scale; however, this approach provides increased power to track site-specific changes in the priority climate indicators that relate the physical and chemical environment (e.g. temperature and carbonate chemistry) to ecological parameters (e.g. calcification and bio-erosion rates) and biodiversity (e.g. meta-genomic analysis of recruitment plates). Tracking broad spatial and decadal-scale temporal trends is the primary climate monitoring rationale, and given the global drivers at play, it is imperative that these data are extrapolated beyond our area of focus. Indeed, in terms of crossing governance scales, trans-national efforts are underway to coordinate our climate monitoring with global efforts, like the Global Ocean Acidification Observing Network. Implementing standardized fixed climate monitoring stations is also currently being coordinated by a multinational coordinating body, the Intergovernmental Oceanographic Commission's Western Pacific Subregion and the Secretariat of the Pacific Regional Environment Program.

Social indicators monitored for the NRCMP are collected independently of the biophysical data. The indicators include a range of socio-economic information relating to coral reef resources, such as residents' perceptions of coral reef ecosystems and management strategies, as well as human–environment interactions (e.g. fishing effort) with coral reef resources, allowing for an enhanced understanding to inform policy that would be impossible using only generalized demographic data (e.g. population density). As social indicator data collection is still in its infancy (it began in 2014), it is premature to delve into trade-offs between the biophysical and social disciplines. We anticipate, however, that the temporal disconnect between these broad data streams may lead to inferential trade-offs in future analyses. Specifically, the sampling interval for NCRMP social indicators is 7 years vs. the biophysical indicators' interval of 3 years. Given funding constraints, the trade-off for increasing the collection frequency for the social data to correspond with the 3-year biophysical collection interval would be a reduction in sample size (i.e. fewer individuals surveyed) to a level not representative of the total population on each island.

Consequently, rather than having all indicators surveyed at the same sites, scale and frequency, each team in the NCRMP uses a sampling design that is based on optimizing the sampling for their indicators (e.g. fish density, coral abundance, water carbonate chemistry or human participation in reef activities). The advantage of this approach is increased precision of the individual disciplinary indicators. And while integrated analysis of the different data streams is possible at the island scale, one consequence of these disparate sampling designs is reduced ability to integrate data streams at levels lower than our common island unit. This could mask smaller-scale variability in the interactions of the multiple ecosystem elements. Similar to how opportunistic funding allowed the fish data to be temporarily integrated from small–large scales (from a watershed bay to the regional data set), smaller-scale interdisciplinary questions may also have to rely on *ad hoc* projects in the meantime.

In sum, the policy environment in which our monitoring programme operates has broadened over time; in response, we adapted multiple data streams to maintain policy relevance without detracting from the overarching goal of long-term coral reef ecosystem monitoring. Next, we recommend how polycentric monitoring could be achieved through better alignment of monitoring efforts and resources across different institutions and scales.

Recommendations

In theory, ecosystem monitoring would be purposefully designed and integrated into the management system. In practice, management and monitoring systems are not always well connected, and as illustrated, priorities evolve over time. Additionally, existing long-term monitoring may be locked into a design that offers little manoeuvrability to trial new methods or depart from established protocols. As demonstrated, these obstacles are not insurmountable, but require adaptable monitoring programmes (and practitioners) that can accommodate improvements in the understanding of what is most important to monitor, while retaining policy relevance by evolving to meet societal and management objectives for the ecosystem. Based on our experience, the extensive and multiscaled data needs of long-term monitoring for ecosystem-based management are not realistically achievable by a single programme, but could be better achieved through a polycentric approach.

At this stage, the most significant hurdles to putting polycentric monitoring into practice are likely to be bureaucratic. Institutional systems and structures tend to be rigid, and establishing new processes to enable cross-scale collaboration and coordination will be a slow process (Samhouri *et al.* 2014). Solving institutional inertia is likely beyond the influence of monitoring practitioners, so to move forward, we have distilled our experiences into three recommendations, implementable within existing polycentric governance structures, to allow long-term monitoring programmes to adapt and stay relevant within the ecosystem-based management paradigm.

CLEARLY DELINEATE ROLES AND RESPONSIBILITIES OF DIFFERENT MONITORING UNITS

With limited resources available, there is the potential that different monitoring units and disciplines will perceive each other as competitors. Early dialogue that promotes understanding of the broader policy drivers for data collection, and increasing the understanding of what data and at what scale each discipline is contributing to these goals, will help to clarify some of these scaling issues and trade-offs. This is particularly important in more disparate fields, like the social and biophysical sciences, where team members often have limited interactions, use different methodologies and may have divergent ontological and epistemological orientations. As Clark *et al.* (2011) outline, the polyglot approach of tasking scientists from different disciplines to problem-solve requires collaboration between people with inherently different world views, seeking and motivated by different agendas. Dialogue between different monitoring units, to clarify the shared goals of data collection, the responsibilities of each entity and their strengths and weaknesses could increase each unit's own appreciation of the wider whole. Facilitated dialogue is more likely to result in the identification of interaction-orientated indicators (Mangi, Roberts & Rodwell 2007), by helping those tasked with indicator development from different fields to better understand and appreciate how their indicators work together to inform a greater whole.

PROMOTE SYNERGISM WITHIN AND BETWEEN PRIMARY MONITORING AGENCIES

Coordination across monitoring agencies could be promoted through a common understanding of the different drivers of information operating at ecological and management scales. Co-creating a conceptual systems model could help identify pathways driving change in the physical, ecological and social components of the system (Yee *et al.* 2015). Interdisciplinary conversations can foster better understanding of the key drivers and outcomes of ecosystem change. This type of collaborative work could assist in identifying data gaps, coordinating collection, merging and comparison of data in a way that can be related across scientific and geopolitical scales to better inform an understanding of the ecosystem. In addition to scale-specific indicators that could continue to be monitored by specific agencies, a core set of complementary indicators could be monitored across all scales (from community–jurisdiction–regional–national–transnational). Synergism like this will require considerable investment to standardize indicators, calibrate disparate methods, develop data management infrastructure and enable formalized community–jurisdictional–federal (in the case of the USA) partnerships. Therefore, integrating monitoring across different levels of governance will require a long-term commitment to working across scales.

PROMOTE SYNERGISM BETWEEN MONITORING AGENCIES AND RESEARCHERS

Strengthening collaborations with universities and research institutions could be advantageous to all parties. Often, monitoring is done by government agencies, which hold considerable leverage to seek and build external collaborations with academics. Conversely, academics, compared to government, have greater flexibility to test new methods or innovative system-level indicators, but may lack long-term time series. These collaborations would strengthen the ability to conduct interdisciplinary monitoring and extend the application and reach of the data collected, as typically academics have greater ability and motivation to publish in peer-reviewed journals. To date, this strategy has served us well, with external institutions validating next-generation molecular sequencing and automated machine-learning approaches to monitor indicators (Beijbom *et al.* 2015; Leray & Knowlton 2015), approaches we did not have the flexibility, expertise or funding to independently pursue.

Conclusions

Generating and integrating ecosystem-relevant monitoring data remains a significant hurdle in operationalizing ecosystem-based management. Coordination and collaboration across disciplines, sectors and geographical, ecological and governance scales has already begun through ecosystem monitoring. However, much more progress towards the active and transparent evaluation of the trade-offs involved in collecting data at different scales for different purposes is needed. By outlining our experiences, we hope to promote increased awareness of the trade-offs implicit in providing these types of interdisciplinary and cross-scale information. By working towards polycentric monitoring of ecosystems, practitioners could orchestrate a monitoring culture more conducive to collectively attaining the information requirements for ecosystem-based management.

Acknowledgements

We thank the extraordinary efforts of those involved in Pacific RAMP. This work was supported by and the authors received funding from NOAA CRCP. Thanks to Mariska Weijerman, Todd Kellison, Sven Kupschus and an anonymous reviewer for comments that improved an earlier draft.

Data accessibility

Data have not been archived because this article does not contain data.

References

Ault, J.S., Bohnsack, J.A. & Mester, G.A. (1998) A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. *Fishery Bulletin*, **96**, 395–414.

Beijbom, O., Edmunds, P.J., Roelfsema, C., Smith, J., Kline, D.I., Neal, B.P. *et al.* (2015) Towards automated annotation of benthic survey images: variability of human experts and operational modes of automation. *PLoS One*, **10**, 1–22.

Clark, S.G., Rutherford, M.B., Auer, M.R., Cherney, D.N., Wallace, R.L., Mattson, D.J. *et al.* (2011) College and university environmental programs as a policy problem (Part 2): strategies for improvement. *Environmental Management*, **47**, 716–726.

Cowan, J.H., Rice, J.C., Walters, C.J., Hilborn, R., Essington, T.E., Day, J.W. & Boswell, K.M. (2012) Challenges for implementing an ecosystem approach to fisheries management. *Marine and Coastal Fisheries*, **4**, 496–510.

Folke, C., Hahn, T., Olsson, P. & Norberg, J. (2005) Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, **30**, 441–473.

Leray, M. & Knowlton, N. (2015) DNA barcoding and meta-barcoding of standardized samples reveal patterns of marine benthic diversity. *Proceedings of the National Academy of Sciences*, **112**, 2076–2081.

Mangi, S.C., Roberts, C.M. & Rodwell, L.D. (2007) Reef fisheries management in Kenya: preliminary approach using the driver-pressure-state-impacts-response (DPSIR) scheme of indicators. *Ocean and Coastal Management*, **50**, 463–480.

Nadon, M.O., Ault, J.S., Williams, I.D., Smith, S.G. & DiNardo, G.T. (2015) Length-based assessment of coral reef fish populations in the main and northwestern Hawaiian Islands. *PLoS One*, **10**, e0133960.

National Ocean Policy (2010) Executive Order, 13547 of Jul 19th, 2010. The implementation plan is available at https://www.whitehouse.gov/sites/default/files/national_ocean_policy_ip_appendix.pdf.

Ostrom, E. (2010) Polycentric systems for coping with collective action and global environmental change. *Global Environmental Change*, **20**, 550–557.

Ostrom, V., Tiebout, C.M. & Warren, R. (1961) The organization of government in metropolitan areas: a theoretical inquiry. *The American Political Science Review*, **55**, 831–842.

Samhouri, J.F., Haupt, A.J., Levin, P.S., Link, J.S. & Shuford, R. (2014) Lessons learned from developing integrated ecosystem assessments to inform marine ecosystem-based management in the USA. *ICES Journal of Marine Science: Journal du Conseil*, **71**, 1205–1215.

Yee, S.H., Carriger, J.F., Bradley, P., Fisher, W.S. & Dyson, B. (2015) Developing scientific information to support decisions for sustainable coral reef ecosystem services. *Ecological Economics*, **115**, 39–50.

Received 19 October 2015; accepted 18 February 2016
Handling Editor: Julia Blanchard

Biosketch

Adel Heenan, Kelvin Goropse, Ivor Williams, Thomas Oliver, Molly Timmers and **Rusty Brainard** work in the Coral Reef Ecosystem Program (CREP) at PIFSC and have been involved in the establishment and implementation of Pacific RAMP. **Marc Nadon** works for the PIFSC Stock Assessment Program. **Arielle Levine** is a Regional Social Scientist for NOAA CRCP involved with the establishment and implementation of the socio-economic component of NCRMP and an Assistant Professor at San Diego State University's Department of Geography. **Supin Wongbusarakum** works in CREP on social dimensions of integrated monitoring. **Paulo Maurin** works for the NOAA Coral Reef Conservation Program, Office for Coastal Management. We dedicate this essay to our co-author **John Rooney** who passed away after this paper was accepted. John was an intelligent, enthusiastic and much valued colleague who will be missed. John led the NOAA CREP Ecospatial Information Team and his significant contributions to map seafloor habitats around Hawai'i, American Samoa, Guam, the Northern Marianas and other U.S. islands, atolls and seamounts across the Pacific will continue to serve as a basis for coral reef conservation and management.