Conservation Biology

Essays

Use of monitoring data to support conservation management and policy decisions in Micronesia

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Abstract: *Adaptive management implies a continuous knowledge-based decision-making process in conservation. Yet, the coupling of scientific monitoring and management frameworks remains rare in practice because formal and informal communication pathways are lacking. We examined 4 cases in Micronesia where conservation practitioners are using new knowledge in the form of monitoring data to advance marine conservation. These cases were drawn from projects in Micronesia Challenge jurisdictions that received funding for coupled monitoring-to-management frameworks and encompassed all segments of adaptive management. Monitoring in Helen Reef, Republic of Palau, was catalyzed by coral bleaching and revealed evidence of overfishing that led to increased enforcement and outreach. In Nimpal Channel, Yap, Federated States of Micronesia (FSM), monitoring the recovery of marine food resources after customary restrictions were put in place led to new, more effective enforcement approaches. Monitoring in Laolao Bay, Saipan, Commonwealth of the Northern Mariana Islands, was catalyzed by observable sediment loads from poor land-use practices and resulted in actions that reduced land-based threats, particularly littering and illegal burning, and revealed additional threats from overfishing. Pohnpei (FSM) began monitoring after observed declines in grouper spawning aggregations. This data led to adjusting marine conservation area boundaries and implementing market-based size class restrictions. Two themes emerged from these cases. First, in each case monitoring was conducted in a manner relevant to the social and ecological systems and integrated into the decision-making process. Second, conservation practitioners and scientists in these cases integrated culturally appropriate stakeholder engagement throughout all phases of the adaptive management cycle. More broadly, our study suggests, when describing adaptive management, providing more details on how monitoring and management activities are linked at similar spatial scales and across similar time frames can enhance the application of knowledge.*

Keywords: adaptive management, communications, community-based conservation, ecosystem management, Oceania

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El Uso de Datos de Monitoreo para Apoyar al Manejo de Conservación y las Políticas de Decisión en Micronesia

Resumen: *El manejo adaptativo para la conservación implica un proceso continuo de toma de decisiones basado en el conocimiento. Aún así, todavía es raro el acoplamiento del monitoreo científico y los marcos de trabajo del manejo ya que las vías de comunicación formal e informal son insuficientes. Examinamos cuatros casos en Micronesia, en los cuales quienes practican la conservación usan conocimientos nuevos en la forma del monitoreo de datos para potenciar la conservación marina. Estos casos se tomaron de proyectos en las jurisdicciones de Micronesia Challenge, los cuales recibieron financiamiento para marcos de trabajo del acoplamiento del monitoreo y el manejo y también englobaron todos los segmentos del manejo adaptativo. El monitoreo en el Arrecife Helen, República de Palao, se catalizó con el blanqueamiento del coral y reveló evidencias de sobrepesca que llevaron a un incremento en la aplicación y la participación. En el Canal de Nimpal, Yap, Estados Federados de Micronesia (EFM), el monitoreo de la recuperación de los recursos alimenticios marinos después de que se implementaran restricciones habituales condujo a estrategias nuevas y más efectivas de aplicación. El monitoreo en la Bahía de Laolao, Saipan, Mancomunidad de las Islas Marianas del Norte, se catalizó con las cargas observables de sedimento proveniente de las prácticas mediocres del uso de suelo y resultó en acciones que redujeron las amenazas agrícolas, particularmente la basura y la quema ilegal, y reveló las amenazas adicionales de la sobrepesca. En Pohnpei (EFM) se comenzó a monitorear después de que se observaran declinaciones en los grupos de desove del mero. Esta información llevó al ajuste de los límites del área de conservación marina y a la implementación de restricciones de tipo de tamaño basadas en el mercado. A partir de estos casos surgieron dos temas: el primero, que en cada caso el monitoreo se llevó a cabo de una forma relevante a los sistemas sociales y ecológicos, y fue integrado al proceso de toma de decisiones; y segundo, que en estos casos los científicos de la conservación y quienes la practican integraron la participación culturalmente apropiada de los accionistas en todas las fases del ciclo de manejo adaptativo. De forma más general, nuestro estudio sugiere que cuando se describe al manejo adaptativo, la aplicación del conocimiento se puede mejorar al proporcionar más detalles sobre cómo las actividades de monitoreo y de manejo están conectadas a escalas espaciales similares y a lo largo de periodos de tiempo similares.*

Palabras Clave: comunicaciones, conservación basada en la comunidad, manejo adaptativo, manejo de ecosistemas, Oceanía

Introduction

Iteratively linking knowledge to action through the adaptive management process has the potential to solve many complex problems in conservation. In this context, we refer to adaptive management as, "flexible decision-making that can be adjusted in the face of uncertainties as outcomes from management actions and other events become well understood" (NRC 2004). The adaptive management cycle typically includes 4 segmented phases: understanding, planning, and prioritizing; acting or implementing; monitoring and analyzing; and adapting and learning (Larson et al. 2013) (Fig. 1a). When an adaptive management system is working well, data collected (knowledge) are expected to be both robust and to catalyze decision making and behavior change (action) in the conservation management context (Cook et al. 2013). Although many conservation monitoring questions can be and are relevant to decision makers (Hutto & Belote 2013), there are only a few published cases that demonstrate how the process of applying adaptive management has improved the usability of monitoring information or the practice and outcomes of conservation (Geupel et al. 2011). A survey by the Conservation Measures Partnership, which consists of 29 member organizations around the world, estimated that although 95% of conservation projects intend to carry out adaptive management, only about 5% actually guide their work by assessing and monitoring their progress (Muir 2010). We explored 4 cases from Micronesia that are among these 5% to highlight the circumstances leading to successful adaptive management and their broader effects on conservation.

There are 2 key challenges of monitoring for decision making in the adaptive management cycle that are addressed well in these cases: reconciling supply and demand of information and reaching a consensus on conservation strategies, actions, and appropriate indicators with multiple stakeholders. These challenges apply equally across the 4 steps of adaptive management. First, it is necessary to reconcile supply and demand of information by answering the questions, do decision makers have a reasonable expectation of science and is science generating information appropriate to the context of decision makers (Sarewitz & Pielke 2007)? To reconcile supply and demand, a diverse group of stakeholders are consulted, including those who generate knowledge and those who are expected to take action based on new knowledge. When this functions well, not only do these groups communicate, they also understand each other (Cash et al. 2003). During this process it can be challenging to reach such understanding and consensus among

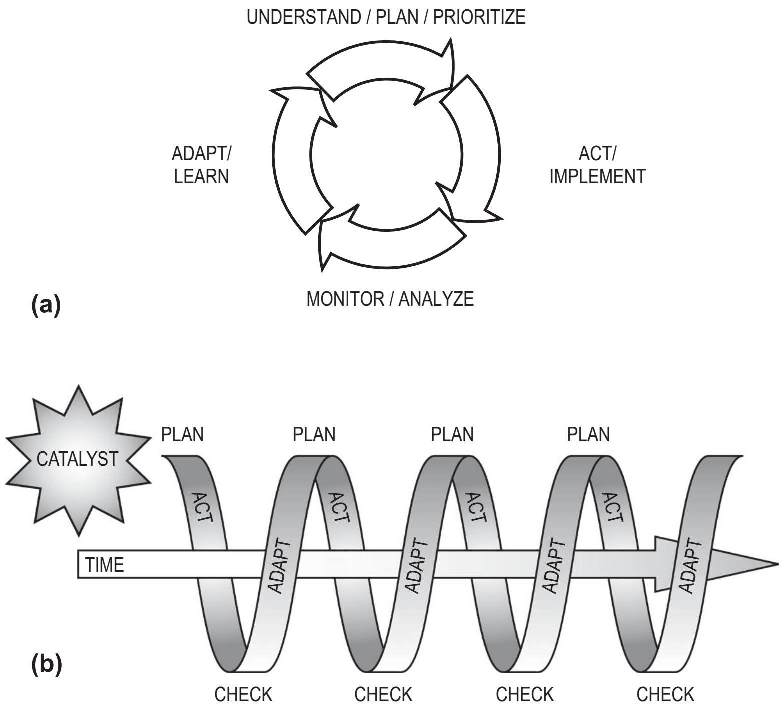

Figure 1. (a) Traditional two-dimensional depiction of the adaptive management cycle and (b) three-dimensional version of the traditional adaptive management cycle in which the cycle repeats over time.

stakeholders without marginalizing outlying perspectives (Layzer 2012). A complex web of multiple stakeholder values suggests logically that at least some of these values and perspectives may shift over time due to changing circumstances and learning (Petersen et al. 2014). These issues of reconciling supply and demand and the dynamic, complex nature of stakeholder values likely contribute to the challenges in successfully applying adaptive management in conservation (Lee 1999; Walters 2007; Nie & Schultz 2012).

Micronesia, in particular, holds special promise for the application of linking monitoring data to conservation decisions through adaptive management for several reasons. First, several exemplary conservation endeavors have been successful and long lasting in this region, in part because customary ways of resource management and resource values were taken into consideration throughout the inception, implementation, and ensuing management of the resource (Brosi et al. 2007; Keppel et al. 2012). Second, certain natural resource managers in Micronesia have based key conservation endeavors on sound ecological baseline assessments that were incorporated into strategic planning exercises (e.g., Herrmann & Gombos 2009; Koshiba et al. 2011). Finally, designs of early monitoring programs have been retroactively assessed to determine what constitutes efficient and sufficient information for management decisions (Houk & van Woesik 2006, 2013; Houk 2009). Prior to extensive monitoring, changes in policy, social acceptance, and ecological responses have been linked with key advances in the supply of information for this region (Richmond et al. 2007; Keppel et al. 2012).

Based in part on some of these successes and in conjunction with Convention on Biological Diversity 2020 commitments, five jurisdictions (Federated States of Micronesia, the Republic of the Marshall Islands, the Republic of Palau, Guam, and the Commonwealth of the Northern Mariana Islands) joined together in 2006 and declared the Micronesia Challenge, a commitment to place at least 30% of nearshore marine and 20% of terrestrial resources under "effective conservation" by 2020 (Remengesau et al. 2006). As part of the regional initiative, signatory jurisdictions agreed to use a minimum number of common ecological and social indicators to evaluate the effectiveness of conservation into the future. This has already led to a regionally standardized sampling design intended to benefit local and regional conservation needs and has been used to collect baseline data to assess both local and regional conservation (P.H., unpublished data).

To identify the sites that achieved the link between science and action within the context of Micronesia, the Micronesia Conservation Trust convened a workshop of practitioners and scientists knowledgeable about adaptive management and monitoring across Micronesia in 2013 in Pohnpei, Federated States of Micronesia (FSM). Participants considered sites within the Micronesia Challenge framework that have received funding for coupled monitoring-to-management frameworks over the past 20 years. We selected 4 cases to examine that encompassed all adaptive management elements (listed above) in the full adaptive management cycle, including monitoring linked to management decisions within the context of the Micronesia Challenge: Helen Reef, Republic of Palau; Nimpal Channel, Yap State, FSM; Laolao Bay, Saipan, Commonwealth of the Northern Mariana Islands (CNMI); and Pohnpei State, FSM. We determined the catalysts for and the monitoring data linked to conservation management decisions in these cases and identified 2 emergent themes that suggest practices related to monitoring for decision support that are ripe for application both in other marine conservation areas and different conservation situations.

Catalysts for Monitoring and Decision Making

The selected case studies emerged from distinct geographic sectors, governance structures, and conservation management histories, and new knowledge (i.e., monitoring data) in these cases was linked to very specific actions (i.e., management decisions) (Table 1). Helen Reef is a remote island archipelago resource under state tenure (Fig. 2a). Ecological and social monitoring was catalyzed by a coral bleaching event, but monitoring led to the discovery of over-harvest of marine resources (Oldiais 2009; Golbuu et al. 2013). Iterative actions reinforced by monitoring included first the declaration of a formal protected area, second increased monitoring and enforcement, and third culturally appropriate outreach programs (Andrew 2011; Republic of Palau 2012).

Nimpal Channel, under customary tenure, was formerly rich in food resources (Fig. 2b). The rumored decline of these resources catalyzed monitoring, which confirmed the threat to livelihoods and biodiversity (Chieng et al. 2011). Iterative monitoring and reporting after creating a no-take conservation area established positive reinforcement of the management action by the community, eventually leading to the construction of a floating nighttime surveillance system (Gorong 2009; Olsudong et al. 2012).

Marine conservation areas in Pohnpei are state run, and iterative monitoring has been used to adapt the boundaries and timings of seasonal closures (Fig. 2c) (Rhodes & Tupper 2007). New courses of action (market-based size class restrictions) have also been posited to decision-makers when monitoring data showed conventional restrictions were failing (Bejarano et al. 2013; Rhodes et al. 2013; P.H., unpublished data).

Laolao Bay represents a government-declared and community-managed conservation area. Iterative monitoring and reporting were catalyzed by observable sediment loads being washed into the bay due to poor land-use practices and by the presence of litter (Fig. 2d) (Castro et al. 2014). Actions taken based on monitoring results reduced land-based threats, particularly littering and illegal burning (SeaWeb 2014), but monitoring also revealed additional threats from overfishing that are currently being shared with stakeholders (Houk et al. 2011).

Emergent Themes

Understanding of Socioeological Systems and Framing of Monitoring Questions

We found that decision makers and scientists in these cases had a reasonable understanding of their social and ecological systems and that monitoring questions were framed to inform their concerns. Several different types of inter-related questions can be answered by conservation monitoring. Conservation monitoring can be conducted for surveillance purposes to document the status of the resources, to detect general trends, or with the intention of haphazardly detecting unexpected impacts, albeit sometimes with very limited statistical power to do so (Nichols & Williams 2006). Monitoring may also be conducted strategically in a management context to inform decision making on the basis of ecological, legal, and other management triggers (McDonald-Madden 2010; Hutto & Belote 2013).

A summary of the strategic monitoring in our case studies is in Table 1. In these cases, decision-makers used ecological baselines and monitoring (Maragos & Cook 1995; Koshiba et al. 2011; Olsudong et al. 2012; Republic of Palau 2012) and socioeconomic assessments (Wongbusarakum et al. 2008; Oldiais 2009; SeaWeb 2014 and references therein) to understand the importance of the ecological and socioeconomic context in which they made decisions. The scientists conducting this research also appreciated the institutional constraints and opportunities in which the information they generated may be applied (e.g., Cash et al. 2003; Layzer 2012; Montambault & Groves 2012). They also recognized that these constraints and opportunities could change over time and that understanding would need to be a continuous rather than discrete process. Whereas the traditional 2-dimensional depiction of adaptive management implies that the decision-making process proceeds over time (Fig. 1a), we found that a 3-dimensional depiction (Fig. 1b) allows for a richer display of the milestones and progress in adaptive management. Information gathering still continues to be guided by the initial catalyst and subsequent planning and action decisions; plans for both state-sponsored monitoring programs and the nascent regional monitoring plan for the Micronesia Challenge are in progress (Chieng et al. 2011; Koshiba et al. 2011; Republic of Palau 2012; Castro et al. 2014).

In each case, the ecological knowledge and decision-making contexts were related (Table 1). In the case of Helen Reef, the nearest inhabited island of Hatohobei is so isolated from the rest of the Republic of Palau that residents, known as Tobians, historically depended on Helen Reef's marine resources for subsistence (Hester & Jones 1974). Geographic isolation required Tobians to maintain extensive marine resources for their sustainability and eventually made these extensive resources a

Table 1. Summary characteristics of monitoring for adaptive management in 4 conservation case studies in Micronesia.

Case	*Location*	*Formal decision-maker*	*Monitoring data used for decision making*	*Corresponding decision made based on monitoring data*
Helen Reef	Republic of Palau	Hatohobei State & Palau National Legislatures	baseline survey in 2000 of coral reef and fish health following the 1998 coral bleaching event and problems with resource depletion due to overharvesting, illegal fishing, and poaching e.g., by foreign fleets (Oldiais 2009; Golbuu et al. 2013)	Hatohobei State declares formal protection status for Helen Reef (Andrew 2011)
				in 2006 Helen Reef joins other marine conservation areas as the Palau Protected Area Network is passed into law requiring that all marine conservation areas receiving funding from the “green fee” tourism tax adhere to a standard monitoring protocol for the explicit purpose of decision making (Republic of Palau 2012); community members trained to support biological monitoring
			coral reef and fish surveys in 2007 replicate the sites of the earlier survey; coral cover on outer reefs significantly increased and coral cover on inner reefs and fish density in either habitat unchanged (Golbuu et al. 2013)	governor of Hatohobei State describes how biological data from iterative surveys of Helen Reef have been the core information used in management decisions (Oldiais 2009)
			socioeconomic surveys show 96% of Tobians support no-take zone in Helen Reef; 60% think resources have increased as result of management actions; 56% believe there is not enough enforcement; and 87% indicate interest in being more involved in management of Helen Reef (Oldiais 2009)	to increase enforcement, an outreach position created within the Helen Reef management board to engage community members and develop community-driven management plan
Nimpal Channel	Yap, Federated States of Micronesia	Councils of Chiefs	anecdotal evidence the preferred reef fish food species were in decline, particularly the bumphead parrotfish (Chieng et al. 2011)	in 2006 a no-take marine conservation area proposed (Houk et al. 2013)
			2007 baseline ecological monitoring (Chieng et al. 2011)	no-take marine conservation area established in 2008 to protect fisheries resources in the 77 ha channel (Houk et al. 2013)
			after establishment, community monitoring revealed night-time fishing was still a problem in the no-take zone (Gorong 2009)	in 2009 community raised funds for and built a floating surveillance platform to monitor illegal extraction (Gorong 2009)
			monitoring in 2012 showed fish biomass in the conservation area was twice that of the reference area, whereas other indicators of coral reef health (coral density and recruitment) were better in the reference areas (Olsudong et al. 2012)	

Continued

Table 1. Continued.

Case	*Location*	*Formal decision-maker*	*Monitoring data used for decision making*	*Corresponding decision made based on monitoring data*
Laolao Bay	Saipan, Commonwealth of the Northern Marianna Islands	CNMI Governor; Civic Leaders	monitoring of sea cucumber population commenced in 1997 in response to depleted stocks on Rota and apparent declining stocks in Laolao (Trianni 2002)	in 1997 Department of Fish & Wildlife closed Laolao Bay to harvest (Trianni 2002)
			Marianna Archipelago Reef Assessment and Monitoring Program (RAMP) surveys conducted in 2003, 2005, 2007, and 2009 adding water quality (Castro et al. 2014), socioeconomic assessments (SeaWeb 2014), and extra sites in response to management requests (Hermann & Gumbos 2009); Coral Reef Resilience monitoring program established 2011 (Castro et al. 2014)	Laolao Bay Conservation Action Plan updated with information from Coral Reef Resilience monitoring program (Castro et al. 2014)
			surveys of human disposed litter showed a decreasing trend in volume after communications campaigns (SeaWeb 2014)	
Marine conservation area network	Pohnpei, Federated States of Micronesia	Pohnpei State Legislature; Traditional Chiefs	spawning aggregations (SPAGs) of groupers monitored and managed using traditional methods for recorded history (Johannes 2002)	by 1990 Pohnpei State government restricted harvest during assumed spawning season (Rhodes & Sadovy 2002)
			annual monitoring of SPAGs reveals continued grouper decline (Rhodes & Sadovy 2002)	in 1995 Kehpara Marine Sanctuary established (Rhodes & Sadovy 2002)
			at least one grouper SPAG ceased to form due to fishing pressure around 1997 (Rhodes & Sadovy 2002)	marine sanctuary expanded (Rhodes & Tupper 2007); market restrictions to control unsustainable fishing gear use (Rhodes et al. 2008)
			annual market survey data (Rhodes & Tupper 2007) and interviews of full-time patriarchal fishers in Indonesia, the Philippines, Malaysia, Palau, Micronesia, Fiji, the Solomon Islands show Pohnpei is 1 of only 2 sites where grouper SPAGs were increasing (Sadovy et al. 2008); continued monitoring reveals no difference in fish density between protected and unprotected sites (Koshiba et al. 2011)	legislature passes size class restrictions on market sales of grouper (Bejarano et al. 2013; Rhodes et al. 2013)

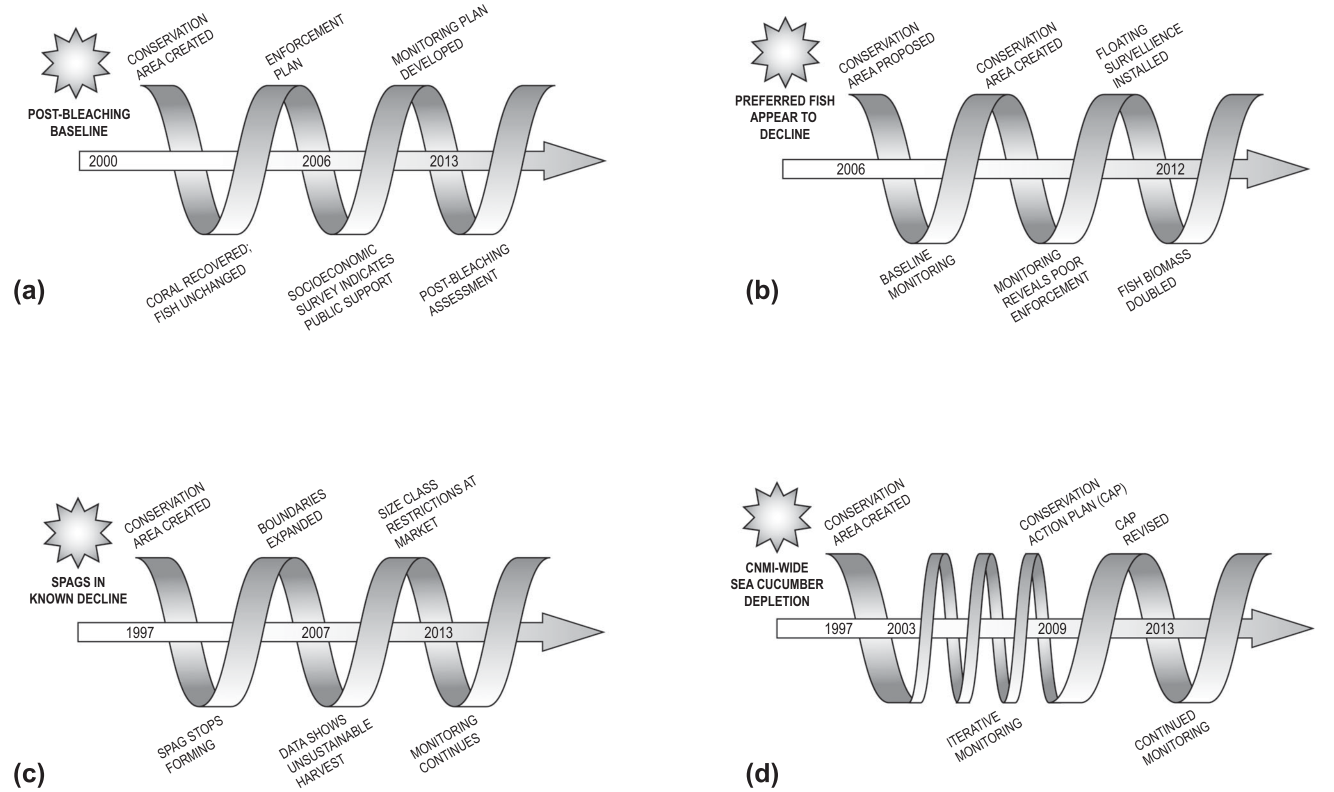

Figure 2. Three-dimensional depiction of adaptive management in 4 case studies: (a) Helen Reef, Republic of Palau, management of coral and reef-based marine life; (b) Nimpal Channel, Yap State, Federated States of Micronesia, management of marine resources for human consumption; (c) Pohnpei State, Federated States of Micronesia, management of grouper spawning aggregations (SPAGS); (d) Laolao Bay, Saipan, Commonwealth of the Northern Marianna Islands (CNMI), management of the effect of pollution and sediment on biodiversity and human well-being. The process starts with the catalyst and proceeds to planning, acting, checking, and adapting.

target of poachers. A coral bleaching event combined with problems with resource depletion due to overharvesting, illegal fishing, and poaching (especially by foreign fleets) highlighted the need for formal conservation efforts (Oldiais 2009; Golbuu et al. 2013). Champions for this cause soon emerged from a combination of formal and informal local leaders who consistently supported the concept of conservation as decision makers began to purposefully examine the success of different types of resource access and restriction (Fig. 2a). This was accomplished through a cycle of monitoring, iterative policy adjustment, and law enforcement based on the data collected by a monitoring design tailored to meet the needs of decision makers (Oldiais 2009).

In contrast to the governance system in Palau, the communities of Nimpal Channel, Yap State, FSM, adhere to a traditional governance system in which the readily accessible marine resources are owned (as opposed to regulated) (Aswani 2005). The customary fisheries management established in Yap means that each community is restricted to a spatial area over which they have clear ownership and responsibility for management and enforcement to maintain sustainable resources (Chieng et al. 2011; Fig. 2b). The perception of responsibility by a particular customary leader was a key enabling condition to commencing the adaptive management process for conservation in Nimpal (Gorong 2009). In both Helen Reef and Nimpal, marine resources are an essential part of household subsistence and income generation, a circumstance that strongly influenced decision makers to engage in conservation and respond to data collected through monitoring.

In contrast to the situation in Nimpal, where a single leader's decision carries the weight of legislation in a traditional society, both Laolao Bay and Pohnpei have state-based governance structures in association with a long history of cultural affiliation with marine resources. The cultural values in both places are complemented by economic concerns: a well-documented market value for reef fish in Pohnpei (Rhodes et al. 2008; Houk et al. 2012) and an influential ecotourism sector around Laolao Bay (Herrmann & Gumbos 2009). Threats to these market values have emerged. In both locales, the reefs appeared to have suffered from overfishing and excessive pollution from a combination of anthropogenic sedimentation and littering, both of which affected water quality and coral reef health (Rhodes et al. 2008; Cuetos-Bueno & Houk 2015). These threats were of concern to different groups of decision makers. In Pohnpei these decision-making groups included members of the general assembly and religious and traditional chiefs (Fig. 2c). In Laolao these groups included the local government and land owners (Fig. 2d). Leaders eventually became champions of market-based harvest size-class limits and sedimentation reduction improvements and anti-littering campaigns in Pohnpei and Laolao Bay, respectively.

In the context of adaptive management, Laolao Bay has the longest running monitoring program, which began after a land-use change event in 1991 that triggered significant water quality concerns and had a negative effect on coral reef health in the bay (Herrmann & Gombos 2009; Houk et al. 2011). Data showed increased sedimentation rates in the coastal waters correlated with degraded coral reef health and both were furthered by socioeconomic assessments that revealed the importance of watershed health to society (SeaWeb 2014). A thoughtful campaign identified "non-traditional spokespeople from [Laolao] Bay, such as fishermen, community leaders and cultural leaders," who reached constituents through venues and media as varied as radio and television spots, flash mobs, martial arts expos, and school and civic society events (SeaWeb 2014). Monitoring in subsequent years contributed to scientific understanding of the coral-reef ecosystem and was a key catalyst for a major infrastructure improvement project to decrease the threat of sedimentation. Currently, a volunteer-based monitoring program aimed at reducing littering (Tasi Watch) continues to complement state-funded ecological and social monitoring efforts in Laolao (Castro et al. 2014).

Monitoring in Nimpal Channel, Pohnpei State, and Helen Reef began through a different catalyst, a region-wide push to establish baseline ecological conditions for the region through a series of rapid ecological assessments (Maragos & Cook 1995; Houk & Starmer 2007; Starmer & Houk 2007; Koshiba et al. 2011). Subsequently, monitoring evolved in a unique way tailored to management and intervention needs for each. For example, the Nimpal community implemented a before-after-control-impact (BACI) design to track the impact of the no-take zone in Nimpal Channel (Olsudong et al. 2012). After seeing these results, much higher fish density and biomass inside the conservation area relative to controls, neighboring communities decided to join in supporting the creation and monitoring of additional community-based marine conservation areas. The relative accessibility of the Pohnpei marine conservation areas allowed a local nongovernmental organization, the Conservation Society of Pohnpei, to support continued, regular data collection and provide feedback for adaptive management.

In Pohnpei, when the monitoring data demonstrated limited biological success, monitoring served to demonstrate where further adaptive management actions were needed. For example, in certain marine conservation areas, it has been problematic to enforce nighttime fishing bans because of limited enforcement resources and the diffuse and clandestine nature of possible infractions (Rhodes et al. 2008). Rather than persisting in the same method of nighttime patrols, the government initiated a new tactic that would allow for a single enforcement location that was highly visible: fish sales at the public market. Monitoring to assess the effectiveness of this new approach is underway. Another decision supported by monitoring data was to change the protected area delineation that included coral reefs but neglected nearshore nursery habitats (Rhodes et al. 2008) and critical terrestrial slopes that contribute sediment that debilitates coral reef health (Victor et al. 2006). As a result, the spatially explicit conservation zones were expanded and altered to better cover ecologically important areas. Helen Reef's remote location limits the frequency of monitoring and the availability of reasonable comparison sites. By focusing on a repeated survey design, areas are surveyed every 3–4 years; thus, managers have time series data with which they can assess a change in status in marine resources over time. The common theme from these examples of adaptive management is that monitoring results have been applied to making decisions to either continue current practices or change the strategic approach.

Communicating in a Locally Appropriate Manner

One widely practiced model of science communication assumes that when decision makers have additional information, they will make the right decision. Decision-theory as applied to conservation, however, demonstrates that information is processed in a highly biased manner, often depending on individual perception of and tolerance for risk and uncertainty (Wintle et al. 2010; Kahan et al. 2011). In addition, behavioral experiments show that people are more likely to believe and act on information presented by a person with whom they have had a prior positive experience (i.e., a trusted informant) rather than on the basis of the actual facts alone (Kahan et al. 2011). However, although there is ample evidence in conservation that much research does not readily transfer to changes in practice (Knight et al. 2008; Cook et al. 2013), the examples from Micronesia show how science data can be effective in a decision-making context.

We observed among our cases (Table 1) that both peer-reviewed journal articles, which add credibility to the project, and local stakeholder engagement facilitated basing iterative management actions on monitoring data (i.e., adaptive management) and developing communications messages and mechanisms that are appropriate for different audiences. Locally appropriate engagement can be working with religious and traditional leadership, conducting social media campaigns, and enlisting champions in the form of both formal and informal leaders. Communications plans have been developed for each island participating in the Micronesia Challenge and are expected to expand and adapt both to site-based needs and the need to communicate different messages to different audiences over time. For example, a series of socioeconomic surveys based on the manual SEM-Pasifika: Socioeconomic Monitoring Guidelines for Coastal Managers in Pacific Island Countries provided data on relationships between the users and the natural resources and the socioeconomic context for expected change in behavior by citizens and practitioners (SeaWeb 2014).

Information from socioeconomic surveys led to greater stakeholder engagement in Laolao than might otherwise have been expected (Herrmann & Gombos 2009), including establishing a volunteer monitoring and outreach program (Tasi Watch). In another instance, outreach by the Conservation Society of Pohnpei (CSP) has focused on highly individualized approaches to communicating results to those people best positioned to become champions in various facets of society. For example, churches are highly influential stakeholders in certain communities in Micronesia (Englberger et al. 2011), and the CSP staff focused on coaching church leaders on the results of data that indicated over-fishing of certain species. These leaders, once convinced, integrated these results into their sermons so new information reached their congregations through a medium they already found believable. In other communities, traditional leaders were more influential, and the CSP staff members were careful to communicate only through appropriate ceremonies and individuals who spoke the traditional high language.

Using the combined authority of traditional chiefs and the church was also applied in establishing the importance of marine conservation areas in Fiji (Clarke & Jupiter 2010). Furthermore, similar trainings bolstered by monitoring data led directly to hiring a community outreach coordinator for Helen Reef who implemented the stakeholder-driven management plan. Even as the state of Yap takes over monitoring efforts previously led by the Nimpal community, the legal governance system ensures that choices made by customary decision makers carry the weight of legislation.

Lessons from Monitoring Linked to Decision Making

We observed that when adaptive management achieves its learning objectives, it involves decision makers with reasonable understanding of their social and ecological systems and scientists who frame monitoring questions to inform their concerns and communicate the results and engage stakeholders in a locally appropriate way. Part of the reason for this is that for people to take action, typically the results of the monitoring need to be couched in a narrative (Leslie et al. 2013) or point of view that resonates with the receiver of the information (Weeks & Jupiter 2013). Typically, adaptive management is shown as a two-dimensional 4 or 5 step cycle (Fig. 1a). Although iterations are implied in this traditional depiction, a three-dimensional representation (Fig. 1b) provides a different way of visualizing the same information that allows the rich history of the original catalyst and subsequent decisions and new knowledge to be viewed. This more comprehensive representation may allow scientists and mangers to better understand the world views of their potential audiences and thus enable them to make their communications and engagements more effective.

As with monitoring, communications and stakeholder engagement plans for specific audiences should be well integrated in every step of adaptive management, with iterative revisions planned if new monitoring data or circumstances suggest the original understanding of the situation has changed. Relatedly, it is our experience that conservation actions are rarely suspended completely during the planning and assessment phases of adaptive management. For example, if a fish population is assessed before and after a temporary opening of a no-take zone, enforcement and other activities that affect the ecosystem and people will continue. In fact, conservation practitioners in Fiji noted that the very presence of researchers in community meetings can subtly influence community members' awareness of how scientific issues and management actions may interact (Weeks & Jupiter 2013). To address these issues, we suggest a representation of continuous adaptation in three dimensions (Fig. 1b) that recognizes the complexity of concurrent monitoring, action, and decision making. In addition, we suggest the implementation of the following two best practices. First, framing of science questions needs to be relevant to both the creators and users of new knowledge in order to increase the flow between knowledge and action. Second, using a locally appropriate approach to engage stakeholders through all adaptive management phases and to share the results may increase their effectiveness at influencing decision and behavioral change in the context of conservation management.

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