A coral reef in a nearshore area in Palau heavily impacted by sediments, showing how stressed they are in sloughing mucus to keep their surfaces clean, but losing the battle, and another, further away from shore that has recovered dramatically from a mass bleaching event that occurred in 1998. Read about coral reef conservation and communication in Robert Richmond’s article. Photo credit R. Richmond.
MAKING SCIENCE MATTER – FORGING EFFECTIVE PARTNERSHIPS FOR CORAL REEF CONSERVATION

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As a graduate student, I received a great formal science education from professors who were brilliant researchers and theoreticians. I learned the key elements of experimental design, how to avoid pseudo-replication, when and when not to transform data, how to calculate an Eigen value, and how to properly format a graph using rub-on letters and lines (I am really dating myself here). What was noticeable missing from my training were the relevance, applications and value of ecological research in a broader applied context. For those of us who have been writing NSF proposals for decades (and occasionally getting funded), the appearance of the “broader impacts” section was a breakthrough of sorts. Initially, it was quite common to see such statements as “there will be broader impacts” in the proposals we were asked to review, and as time went on, such statements had to be much more explicit (to the chagrin of many P.I.’s).

The value of basic research is undeniable, and many research efforts that were initially purely academic in nature have lead to major breakthroughs in applied science, from medicine and agriculture to conservation biology. It is the major shift among researchers to value scientific communication skills that I find both notable and a cause for optimism, especially in a world of rapid change at both the local and global levels, and at a time when science is often under attack for political reasons.

As a coral reef scientist whose career began as an undergraduate student studying Caribbean coral reefs in 1974, I never would have imagined the dramatic declines that I have personally witnessed over the past four decades. Having had the opportunity to study coral reefs around the world, including areas devastated by mass coral bleaching events, it was mind-boggling to see centuries and millennia of reef development, evolution and growth destroyed in weeks to months due to a combination of both local and global level stressors. Yet, I remain optimistic that science, when properly disseminated and applied can provide the key information necessary to change the present trajectory. Bridging science to policy development, implementation and evaluation will be essential to leaving a legacy of vital coral reefs for future generations.

It is impossible to study coral reefs without being acutely aware of the ecological, cultural and economic impacts of coral reef losses on those human communities who depend on these exquisite ecosystems. Having had the opportunity to learn from traditional fishers and stakeholders from the Caribbean and Pacific Islands certainly heightened my awareness of the human dimension of coral reef research and the critical need to blend elements of traditional ecological knowledge with the best of modern science to tackle coral reef decline. Many cultural prac-

Fig 1. The six-step processes involved in reef replenishment of corals, including synchronous spawning of conspecifics, successful egg-sperm interactions leading to fertilization, larval development, larval-substratum interactions, settlement and metamorphosis of a larva into a primary polyp of a new colony and acquisition of symbiotic zooxanthellae.
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CORAL REEF PERSISTENCE

The persistence of coral reefs depends on the success of two key processes: reproduction, the formation of new individuals from prior stock, and recruitment, the process by which these new individuals join the population. In the case of corals, the building blocks of coral reefs and the major structural habitat component for fish and invertebrates, water and bottom quality are key. The majority of reef-building corals are simultaneous hermaphroditic spawners, releasing eggs and sperm into the water column during limited periods each year (for some species, as limited as one 20-minute episode annually). Development times from fertilized embryo to competent planula larvae can take 18–72 hours, depending on the size of the egg. Following this development period, larvae begin search for a suitable place to settle and metamorphose into the primary polyp of a new colony. Recruitment is mediated by the presence of specific cues that serve as metamorphic inducers. For most spawning corals (as opposed to brooding species that release fully developed planula larvae), the newly settled recruits must acquire their symbiotic algae (zooxanthellae) responsible for most of their nutrition via photosynthesis from their surrounding waters. As such, there six distinct, chemically-mediated steps involved in coral reef replenishment that must succeed in order for reefs to persist: synchronized spawning of conspecific coral colonies,
fertilization of eggs by sperm from a different colony of the same species, development from an embryo into a competent planula larva, movement from the water column to an appropriate benthic habitat, metamorphic induction into a benthic polyp and acquisition of zooxanthellae (Fig. 1). All of these steps are mediated by water and bottom quality, and the disruption of any one step results in the failure of coral populations to be replenished.

This quick burst of coral reef science is presented to highlight the importance of local actions to support coral reef health, persistence and resilience. Local efforts to control coastal runoff, associated sedimentation and pollution are essential to the future of coral reefs. Maintaining adequate populations of reef herbivores, both fishes and invertebrates, is also an essential element for supporting reef health through controlling fleshy algae, and the establishment (and associated enforcement) of networks of marine protected areas (MPA's) helps to achieve this critical goal, with the caveat that due to land-sea interactions, MPA’s will fail to meet the targeted objectives without associated protections and proper land-use practices within adjacent watersheds.

There is a wide range of stressors affecting coral reefs, from acute to chronic and the subtle to the catastrophic. I spent two years performing my doctoral dissertation research on Enewetak Atoll, Marshall Islands, which was ground zero for nuclear tests during the 1950’s. Vaporization via hydrogen bomb is among the stressors that I consider in the catastrophic (and acute) category. Bomb craters over a mile in diameter and 100 feet deep are part of the nuclear testing legacy at Enewetak, but large and small corals and abundant fish populations can be found in these anthropogenic features. In contrast, several Caribbean reefs that I studied starting 40 years ago have lost over 90% of their coral cover and fish, and will never recover from the chronic anthropogenic impacts of sedimentation, coastal pollution and overfishing superimposed over episodes of disease and from mass coral bleaching tied to global climate change unless we effectively change the human behaviors responsible for these losses. In reality, we can’t really manage coral reefs, only the human activities causing their decline.

Numerous studies and associated data have clearly demonstrated substantial coral reef losses worldwide, and the expectation is for losses to continue and accelerate due to the increasing impacts of climate change and the associated problems of elevated seawater temperatures leading to mass bleaching events, rising sea levels with increases in coastal erosion, ocean acidification with reduced calcification rates and increased storm intensities with associated physical damage and coastal water quality effects. This is hardly a cheery picture of the future of coral reefs and those that depend on them.

COMMUNICATING SCIENCE AND BRIDGING SCIENCE TO POLICY

The bridging of science to management for coral reefs (and many other ecosystems) has been successfully occurring for much of the past two decades. While serving on the organizing committee for the 7th International Coral Reef Symposium (ICRS) on Guam in 1992, we received some serious pushback on the inclusion of management-focused sessions from researchers who clearly felt that the focus of these meetings should be limited to “serious science” and that management belonged to a different realm. Efforts at this meeting to hold sessions targeting reef managers and open to the broader community of stakeholders proved successful and by the 11th ICRS in Ft. Lauderdale, Florida, in 2008, over 50% of the sessions had management implications and applications. This shift in direction and allocation of effort has not impacted the quality or quantity of science being produced, but rather it has vastly enhanced the value.

Efforts at communicating science to broader audiences have been expanding, with numerous programs and opportunities now provided to scientists willing to engage in such activities. The Leopold Leadership Program (http://leopoldleadership.stanford.edu/) provides fellowships and training for mid-career environmental scientists to learn how to be more effective in their outreach and broader education efforts. Specific areas include how to speak with policy makers, write articles for the popular media, effectively handle interviews and partner with journalists. The American Association for the Advancement of Science has a dedicated section on their website with excellent materials (http://www.aaas.org/page/communicating-science-resources). Sea Web (http://www.seaweb.org/home.php) and COMPASS (http://www.compassonline.org/) are two organizations that are dedicated to enhancing scientific communication on ocean-related issues. Also, a number of books have been published on the important topic of scientific communications, which are great for both established professionals as well as graduate students willing to more fully engage with a variety of audiences. Four of my favorites include “Escape from the Ivory Tower,” (Baron, 2010), “Science as a Contact Sport,” (Schneider, 2009), “Merchants of Doubt,” (Oreskes and Conway, 2011) and “Am I Making Myself Clear,” (Dean, 2012).

As coral reefs are widely distributed across the globe, they are found in a variety of countries with unique cultures, many of which have attributes that support sustainable practices, and provide more broadly applicable lessons in conservation action.
planning and program implementation. Many Pacific Islands are notable for their marine tenure systems, where villages own reefs outright. In such systems, traditional governance is often at work, where rules are promulgated by chiefs, master fishers or councils, and enforcement occurs through voluntary compliance and peer pressure. Ownership translates into clear lines of responsibility. This is in stark contrast to western systems, which are reflective of the "tragedy of the commons," where all have ownership, but none take responsibility. These island communities are also typified by a firm concern about intergenerational responsibility and a commitment to insuring a sound resource legacy for their children and grandchildren.

An example of a solution that evolved from the partnership among scientists, communities and local leaders in Palau is the modification of taro farming practices to protect coastal reefs from runoff and sedimentation while enhancing local food security (Fig 3). Palau, like most islands, is highly dependent on food imports, and should shipping be disrupted, serious problems will result. Many taro fields have fallen into disuse, and others in low-lying coastal areas traditionally used for such farming were flooded by seawater following recent typhoons, a situation that is expected to worsen as a result of global climate change. By modifying practices, including using a better design to trap sediment, reinvigorating fallow fields and moving these higher up into the watershed to trap water before the volume and velocity of runoff become too great, it is possible to protect reefs from sedimentation in an economically feasible and culturally acceptable manner (Koshiba et al., 2014).

Many of my colleagues and I have worked at the intersection of science, community engagement and traditional leadership with a range of positive outcomes achieved largely due to the strength of the partnerships and the clear focus on operating through a consensus process (Richmond, et al., 2007). By determining the overall goals and objectives of key stakeholder groups, in our case a balance of coral reef resource use and sustainability, it was possible to identify the specific outcomes hoped for, and how each partner could contribute to overall success. Through respectful and transparent engagement, candor, frequent feedback, and clear communications, research empowered those active in the decision-making process with the information needed to achieve their desired outcomes.

In my 36 years of experience in working with island communities and their leaders, I have found these stakeholders and decision-makers to be outstanding partners with which to work as a researcher. The foundation of such partnerships is mutual trust and respect, which takes time to build, but once established (and honored) can provide unparalleled opportunities for putting science to work in a meaningful way. As an "outsider," it is not my role to tell communities what is right or wrong, as these are their decisions based on their local cultures, goals and aspirations. Rather, my other expatriate research colleagues and I are most effective as sources of objective information who can help address expressed concerns, and by operating in a supporting role, can provide the data foundational to informed decision-making. Full engagement with local communities, experts, agencies and institutions is also important, listening carefully to priority requests and data needs, and partnering with their culturally connected practitioners to insure communication of data and options is clear to all of their target audiences. Efforts at building local capacity through partnerships and mentoring are extremely important to achieving positive outcomes, and are always of mutual benefit for those scientists desiring to see their research and knowledge put to work (Fig 3).

As scientists, it is important to recognize one's weaknesses as well as strengths, and use this understanding as the basis for strengthening the effectiveness of partnerships in collecting, interpreting, communicating and applying data to real-world problems. In cross-cultural settings (including science to policy in a western culture; Washington D.C. has a culture as unique as any), it is not only the message, but also the selection of the messenger that can lead to success in achieving a positive outcome. Leaving egos and logos behind is also a means of building bridges among partners, with an understanding that much can be accomplished if the focus is on the outcome rather than the credit.

After four decades of studying corals reefs, some that have been totally devastated, and others that are still in exceptionally good condition, it is clear that the future of these exquisite ecosystems is tenuous at best. At the last ICRS in Cairns Australia (2012), a group of coral scientists, under the auspices of the Center for Ocean Solutions, Stanford University (http://www.centerforoceansolutions.org/) developed a Consensus Statement on Climate Change and Coral Reefs (http://www.icrs2012.com/Consensus_Statement.html), which has been signed by over 3,200 scientists. The effort focused on what we do know, rather than what we don't, and on the need to effectively reduce local stressors now to buy time to address climate change, which will ultimately impact reefs worldwide at an unprecedented level. The backing of such a large group of scientific experts empowered many island leaders to work through their policy organizations such as the Association of Pacific Island Legislatures, the Council of Micronesian Chief Executives and the Pacific Islands Forum to pursue and approve their own resolutions on climate change. This continuing dialog between senior policy makers and scientists will be a foundation for the 13th ICRS to be held.
in Hawaii in June, 2016 and efforts to further bridge science to policy.

Ultimately, it is impossible to make sound decisions without adequate and accurate information. Providing such is the province of science. Clearly communicating science to a variety of targeted audiences is critical to the future of our planet, and the world’s ecosystems under duress. For coral reefs, I believe that if we leave these ecosystems in their present state as a legacy for future generations, we will have failed as a society. I say this not only as a scientist, but also as a parent. To me, the joy of science is seeing results put to good use, and getting beyond the identification of problems, to the development and implementation of solutions. This can only occur if we are good partners and good communicators.

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