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Lessons for Minimizing Impacts to Coral Reef and Other Ecosystems from the 2004 Tsunami

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Abstract.—The 2004 Indian Ocean tsunami left a vast amount of destruction in its wake on land and in the sea. About 60% of coral reefs in the affected areas of Thailand were damaged, at least in the shallowest 10–20-m (33–66 ft) depth zones. Many damaged reef, beach, and mangrove areas in Thailand and Sri Lanka were high value tourist attractions or provided other important ecosystem goods and services. We were part of a fortuitous partnership of people with experience in reef restoration, coral reef science, marine debris removal, construction, professional scuba diving, business, marketing, and environmental nongovernmental organizations. We helped organize and fund multiple restoration and cleanup projects that restored damaged and detached sea fans in Similan Islands Marine National Park, restored hard corals, removed more than 453.59 metric tons of marine debris, and provided sustainable management advice to local stakeholders and decision makers. We later became involved in advising emergency management agencies on disaster preparedness and response. We use our reef-dominated experiences as a case study to suggest broader lessons learned for natural scientists to be involved in and for emergency managers to consider for mitigating and planning for future natural disaster impacts on fishery ecosystems. We also provide some coral-reef specific lessons regarding reattachment of large sea fans, triaging and organizing large-scale volunteer marine debris recovery, and other coral ecosystem restoration efforts. We argue that "natural" disasters can cause significant damage to reefs and other ecosystems and that much damage results from human sources that are not natural and can be mitigated or prevented (such as siting and land-use decisions that lead to debris affecting reefs). Thus, we disagree with those who say natural events like hurricanes or tsunamis "are not appropriate for reef restoration" (Precht 2006; Symons et al. 2006). Further, governments need to recognize the economic and inherent values of ecosystem goods and services in natural disaster response legislation and policies (e.g., The Stafford Act in the United States) to improve outcomes for society. We also argue that ecosystem advocates need to adopt the language of emergency management.

Introduction

In this chapter, we want to briefly summarize our experiences responding to the effects of the 2004 Indian Ocean tsunami on coral reef and other ecosystems. We will then use more detailed examples of that and our subsequent work in the field of natural disaster emergency management as a case study to draw a series of broader policy lessons learned and recommendations to improve planning and postevent actions for future natural hazards affecting fishery ecosystems. Our goals are to convince ecosystem specialists of the

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ways in which their participation in this field is needed and to convince emergency managers of the need to more fully consider ecosystems in emergency management.

First, we wish to provide full disclosure about our involvement and motivations regarding responding to natural disasters as we are both survivors of such disasters and those experiences undoubtedly color some of the views that we express. D.B. survived a 1997 pyroclastic event of the Soufirere Hills Volcano in Montserrat (deborahbrosnan.com). D.M. was actually in Khao Lak, Thailand on the coast when the tsunami hit and was washed 1 mi by the wave (Emmons and MacFarlane 2005; Hannemann and Lehmkuhl 2005; Meadows 2005).

After the tsunami, we began consulting with professional ecologists, scuba divers, fishermen, aid agencies, nongovernmental organizations (NGOs), and business and community leaders in the affected regions to help them respond to the effects of the disaster. We learned that there was significant reef damage in many areas (Brosnan 2005; Wilkinson et al. 2006). D.B. quickly established the Tsunami Reef Action Fund (TRAF, tsunamireefactionfund.org) as an offshoot of the Sustainable Ecosystem Institute (SEI) to help individuals, communities, and ecosystems get back on their feet. She also took advantage of SEI's Conservation Science Network group of professionals that had been previously established under SEI's umbrella to serve as a resource for events of this nature (http://www.sei.org/prlist.html). We provided technical guidance in areas that we had expertise in, including hard and soft coral restoration, marine debris removal, sediment removal, and dealing with net entanglement hazards. We also provided supplies, equipment, funding, encouragement, and links to other experts. We each made multiple trips to affected areas of Thailand and Sri Lanka where we provided further assistance and hands-on help. We consulted and assisted in field projects: to remove marine debris that was damaging reef and sandy beach habitat in the area of Khao Lak, as well as the more well-known tourist islands of Phi Phi in Krabi province, Thailand and a number of locations in Sri Lanka and the Maldives; to restore damaged hard corals; to work with local communities to help them sustainably manage and conserve their reef ecosystems; and to reattach giant sea fans Annella spp. in the Similan Islands National Park in Thailand. Annella sea fans in the Indian Ocean are very large, often 2 m (6.6 ft) in diameter, and reattachment of such large individuals had not been attempted before. We had success with three methods utilizing epoxy glue, cement, or stainless and plastic hardware to bolt the seafans into the substrate using pneumatic tools (see Brosnan 2005 for details).

The results of our efforts were substantial (Brosnan 2005; Petchrung 2006; http://www.tsunamireefactionfund.org): more than 453.59 metric tons of debris were removed from the marine environment by our partner groups (see Phi Phi Dive Camp at http://www.phiphidivecamp.com, Tsunami Volunteer Center at http://www.tsunamivolunteer.net, and the Ecotourism Training Center at http://www.etcth.org), hundreds of corals were uprighted and hundreds more fragments were transplanted to begin restoration efforts, 353 sea fans were reattached with 74% survival (Petchrung 2006), dozens of local people were provided income-producing jobs, and hundreds of local and international volunteers learned new skills and an appreciation for the benefits of healthy marine ecosystems. Additionally, many new projects and initiatives have begun that trace their roots to our efforts, including ReefCheck reef training and monitoring groups, an experimental coral nursery, and artificial reef deployment, to name a few.

Despite the successes of our work described above, we also know that much more could have been accomplished had we been better prepared. We fear that more unnecessary damage to coral reefs and other aquatic ecosystems will occur if we do not improve our readiness for future events. In addition to our experience in responding to the tsunami, we have worked on responses to other natural disasters, including hurricanes, floods, and volcanic events. D.M. has also been trained by the Federal Emergency Management Agency (FEMA) in emergency response processes and works with emergency managers at the State of Hawaii Civil Defense Office and the National Tsunami Hazard Mitigation program of the National Oceanic and Atmospheric Administration. These experiences have shaped our views on the ways in which scientists and emergency managers can work together better to minimize and mitigate impacts of natural disasters on ecosystems.

Should We Respond to and Restore Ecosystems Damaged by Natural Disasters?

Despite our accomplishments and those of others involved in restoration work after the tsunami (see Barbier 2006; Phongsuwan et al. 2006; Wilkinson et al. 2006), multiple authors in the excellent book, Coral Reef Restoration Handbook, edited by William Precht (2006), argue that "natural" events like hurricanes or tsunamis "are not appropriate for reef restoration" (Symons et al. 2006). This is the only book on the topic and seems to reflect a fairly widely held view in the coral restoration community, so we want to quickly provide our own counterpoint to this view.

The foundation of the view of the authors in Precht (2006) seems to be the notion that coral reef organisms have adapted to the periodic disturbance regime of hurricanes and tsunamis (however, see Scheffers et al. (2006) for a possible example of a Holocene tsunami that led to a phase shift from a reef dominated to an algal-dominated community). While we do not dispute that reef organisms have usually adapted to these natural disturbances, the current situation is more complex in ways that may require human intervention. First, their notion assumes an ecosystem that is not significantly affected by human activities. However, this is not the situation in many ecosystems today. Multiple authors have concluded that coral reefs are under threat from human activities globally and that 80% of reefs in Southeast Asia are considered at risk from human impact (Spalding et al. 2001; Burke et al. 2002; Wilkinson 2004). More specifically, there is mounting evidence that the frequency of tropical cyclones is increasing in recent years (Webster et al. 2005; Holland and Webster 2007) and that this may be due to human influences, including global warming. The combined effects of human impacts and more frequent natural disasters may overwhelm the resilience and adaptive capacity of reef organisms.

Our work from the tsunami removing 453.59 metric tons of debris, including a variety of petroleum products, plastics, and other chemicals, and fishing nets, also shows that large amounts of human byproducts are now part of the aftermath of so-called natural events. As this human-generated debris can cause significant physical damage, smothering, and chemical pollution to coral reefs and other ecosystems (Petchrung 2006; Wilkinson et al. 2006), the distinction between natural and anthropogenic events is blurred. The amount of debris recovered by our collaborators is roughly equivalent to the amount of marine debris, mostly derelict fishing nets, removed by the U.S. government and partners from the northwestern Hawaiian Islands at a cost of more than US$15 million (National Oceanic and Atmospheric Administration, unpublished data) over the past 10 years or so to decrease impacts to coral reefs and endangered monk seals and sea turtles. Further, the U.S. government estimates that hundreds of millions of tons of debris were left in the marine environment after the hurricanes of 2005, and this debris is affecting both the economy and ecosystems (NMFS 2007 and Gaude et al. 2008; Osborn et al. 2008; both this volume). In addition, there is growing evidence that coral reefs are less resilient to stressors than they used to be because of the negative impacts of multiple simultaneous stressors, including climate change, coral bleaching, fishing alterations to food webs, decreased water quality, overcollection of reef organisms, and boat strikes (Wilkinson 2004; Grimsditch and Salm 2005). Thus, the assumptions inherent in chapters of Precht (2006), that natural events require no response may cause us to fail to take action when it is needed and thus hasten the demise of vital ecosystems and processes, exactly the opposite of what is intended (Brosnan 2005; Petchrung 2006).

A different point is made by Adger et al. (2005) who argue that the "upsurge in investment in artificial rehabilitation of reefs is misguided because it fails to reverse the root causes of regional-scale degradation." While we agree that some proposed solutions are overengineered, expensive, and of small scale, we believe that development of such restoration technology is a valuable component to broader efforts aimed at comprehensive conservation and restoration of ecosystem services and that many "triage" efforts of rerighting and stabilizing large coral heads are worthwhile. We cannot improve our success in such efforts without real-world trials so that reef restoration can reach the level of success of silviculturists on land (Rinkevich 2006). While attention does need to be focused on regional-scale degradation as well, at a minimum, artificial rehabilitation can slow or halt declines in ecosystems while all other threats are addressed. Additionally, Adger et al. (2005) and others make the unjustified assumption that aid investment, and particularly volunteer labor, are part of a zero sum system where investment in one effort precludes investment in other efforts because of limited funding. It is our sense that many of the volunteers and donors who helped to recover ecosystems after the tsunami, ourselves included, would not have otherwise donated the time and money we did to other worthy, but nontsunami related, conservation causes. Such added investment can then enhance overall ecosystem function at no real cost to other conservation efforts, if such investments are not zero-sum.

Given all of the above information, we conclude that a wide variety of efforts to restore the resilience of, and recover, coral reefs and other ecosystems after natural disasters can be successful and should be attempted under appropriate conditions. Many of these conditions are described more fully in examples below.

Adopting the Language of Emergency Management

The current philosophy of emergency preparedness revolves around all or multihazard planning and preparedness rather than the earlier model where emergency managers developed separate, and sometimes incompatible, response plans and processes for each type of natural or anthropogenic disaster (FEMA 1996). Disaster managers organize their work around the four phases of the disaster cycle (Figure 1) formally called the preparedness, response, recovery, and mitigation phases. One of our overarching goals in this paper is to help raise the understanding of the importance of considering natural resources and ecosystems in emergency management planning. To do this, we suggest that the ecological and restoration community more fully adopt the language and protocols of the emergency management profession. In particular, the terms response, recovery, mitigation, and preparedness have specific meanings in the context of emergency management that may differ from those used by ecosystem specialists and may cause confusion as natural sciences and ecosystems become more widely considered by emergency managers and decision makers. The term "mitigation" in particular has somewhat different meanings for environmental professionals versus emergency

Figure 1. Diagrammatic representation of the disaster cycle.

managers. For environmental professionals, mitigation has regulatory and common usage meanings that are often synonymous with dealing with planned development projects or decreasing impacts of some other unintentional anthropogenic causes. For example, wetlands mitigation often involves actions to improve or produce new wetlands in areas as a result of planned destruction or harm to wetlands elsewhere. For the U.S. government, environmental mitigation is defined in federal regulations (40 CFR 1508.20) to include (a) avoiding; (b) minimizing the impacts by limiting the magnitude or degree; (c) rectifying the impact by repairing, rehabilitating, or restoring; (d) reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action; and (e) compensating for the impact by replacing or providing substitute resources or environments. This definition used by the federal government includes parts of the response, preparedness, and recovery phases used by emergency managers. For emergency managers, mitigation means actions that "involve lasting, often permanent, reduction of exposure to, probability of, or potential loss from hazard events" (FEMA 2006). The following discussion further highlights these differences.

As a cycle, there is no starting point to the disaster cycle, but the mitigation phase is often the first one to be considered. The mitigation phase in emergency management involves efforts that are made to decrease the potential severity and impact of future disasters or hazards. This can happen in the immediate aftermath of disasters, but also happens in between disasters as part of the regular review and prioritization process. The Preparedness phase includes actions to prepare people, equipment, and plans for dealing with disasters and other hazards. There can be a subtle distinction here, and even overlap, between the mitigation and preparedness phases and actions. Preparedness, however, is seen as the planning phase to deal with the inevitable nature of natural disasters and other events, while mitigation involves positive actions before an event to decrease impacts of these events. For example, moving or building new critical infrastructure facilities like hospitals or power plants outside of hazard zones is seen as mitigation as any future hazard (e.g., earthquake) would likely have less of an impact on a community while related preparedness activities would involve developing plans and contingencies to respond to a disaster affecting a hospital in the hazard zone by being prepared to evacuate patients to another hospital outside the hazard zone.

The next phase is the response phase, which includes the time just before a disaster (if there are warning signals of the approach of a hurricane or tsunami) and also the immediate aftermath of an event. It is during this time that contact is made with survivors, and food, medicine, water, safety, and shelter are provided and the damages associated with the event are stabilized and assessed. The next phase is recovery, which involves the restoration of basic infrastructure and services and proceeds until the community has regained some semblance of original function. The origin of the recovery phase is fuzzy as response actions and recovery can overlap to a large degree, but the difference in actions and intent is clear.

Thus, while the title of this symposium only addresses the mitigation of natural hazards, we will comment on, and draw lessons relevant to, all phases of the disaster cycle. In fact, we will organize the rest of this paper around those four phases, and we begin with the preparedness phase. We provide a summary of policy lessons learned for each phase discussed in this section in Table 1. The lessons learned are sorted by those appropriate for ecosystem specialists and those more appropriate for emergency managers.

Preparedness Phase

Policy and Legislation Issues

Probably the most important preparedness measure that can be taken at local, regional, and national levels is to recognize the economic contributions of ecosystem goods and services to the overall economy of a region or country. Much recent work has

Table 1. Summary of disaster cycle phases and policy lessons learned grouped by actions that can be taken by ecosystem specialists versus emergency managers.

Preparedness	Ecosystem specialists	Emergency managers
Policy and legislation		
Ecosystem goods and services	Advocate importance; help calculate values.	Recognize importance and link to community recovery; advocate for full inclusion in emergency management process.
National Incident Management System and national response plan	Advocate for inclusion of trained ecosystem specialists in NIMS, NRP, and other planning.	Advocate for inclusion of trained ecosystem specialists in NIMS, NRP, and other planning.
Natural resource agency processes	Encourage agency leadership to develop all-hazard disaster response programs.	
Planning		
Technical expert networks	Join and/or develop local or regional networks of experts.	Partner with natural resource agencies, professional groups, and networks.
Spatial and temporal scale issues	Provide emergency managers understandable information on scales of potential or actual disasters.	Solicit detailed information on ecosystem impacts of high priority disasters.
Local/regional pool of emergency response materials	Help organize and develop equipment and supply repositories for emergency response.	Support development of natural resource emergency response materials.
Methodology online library	Support development and contribute material.	Support development and promote use postdisaster
Response		
Damage assessment survey	Contribute to program protocol development.	Support program development; integrate in plans.
Volunteer ecosystem restorers	Organize and train response volunteers.	Support and integrate volunteer responders.
Recovery		
Local/regional ecosystem priorities	Participate in planning; ensure all issues considered.	Encourage participation; include in plans.
Improved restoration techniques	Develop, test, and improve methods; advocate for funding.	Advocate for funding.
Postevent regulation	Assist in planning for possible scenarios.	Solicit input from ecosystem specialists.
Monitoring	Organize and participate in developing monitoring protocols.	Support development of monitoring program.
Mitigation		
Land-use planning	Point out implication of land-use plans for ecosystems.	Solicit input from ecosystem specialists.
Zoning laws	Point out implication of zoning laws for ecosystems.	Solicit input from ecosystem specialists.
Education	Provide understandable information for a variety of audiences.	Make education a high priority

been done in this area overall (Costanza et al. 1997; Balmford et al. 2002) and for coral reef resources in particular (Cesar 2000). Cesar et al. (2003) found that goods and services from coral reefs provide a yearly net benefit of $30 billion worldwide. Costanza et al. (1997) showed that the value of clean water, shoreline protection from waves, habitat, tourism, and so forth from natural ecosystems is greater than the worldwide gross domestic product. Yet, understanding and utilization of this information is still limited to specialists already interested in these facts and has not penetrated far into the policy or legislative arenas. In our work in Thailand, the economic impact of tourism and scuba divers was a major factor in the decision of the government and stakeholders to focus efforts on seafan restoration as the seafans are considered a major part of the tourist attraction for scuba divers in the Similan Islands National Park. However, most of our work was not government-funded, and prioritization was more based on the interests and abilities of the project staff, volunteers, and funders, with only some thought given to ecosystem services. Since the tsunami, the government of Thailand has invested in artificial reefs and breakwalls off a long stretch of the open coast off Khao Lak and further south, partly in hopes of using those reefs to mitigate the force of potential tsunami and storm waves in the future. International agencies are also organizing efforts at mangrove restoration, based in part on the shoreline protection some authors found they provided during the tsunami (Danielsen et al. 2005; Kathiresan and Rajendran 2005; Vermaat and Thampanya 2006; but see Kerr et al. 2006 and Kerr and Baird 2007).

However, recognition of the value of ecosystem goods and services has not penetrated to the level of preparedness prioritization for future disaster scenarios as it should, either in Thailand or in the United States. In the United States, the major law dealing with emergency management is the Stafford Act, which is primarily administered by FEMA. This act establishes the framework for disaster preparedness and mitigation plans and programs as well as postdisaster assistance programs. Assistance is provided for individuals, communities, debris removal, and, in some cases, small businesses, but there is no assistance explicitly for ecosystems. In fact, the Stafford Act is entirely silent on the role of ecosystems in disasters (beyond exempting some reconstruction projects from the requirements for National Environmental Policy Act [NEPA] review), though the act does consider impacts on public and private property and income. Indeed during emergencies, the NEPA environmental impact statement (EIS) process is often seen as a hindrance rather than a tool. However, in an EIS process, Brosnan (unpublished manuscript) documented the habitat destruction and loss of essential ecosystem services (subsistence fisheries and tourism) that would result from the destruction of a coral reef in order to build an emergency structure during a volcanic eruption. Through extensive individual and NGO advocacy, the lost ecological services were factored into the decisions and successfully mitigated. Thus, the outcome depended entirely on chance involvement of key scientists and policy makers and government funders rather than any considered policy or procedure.

However, Gaude et al. (2008) describe efforts where emergency responders and a Sea Grant fishery extension agent were able to work within the FEMA framework in the aftermath of the 2005 hurricanes under the notion that the economic livelihood and/or property of fishers was being affected. This ad hoc collaboration, based on the specific personnel involved in this one situation, did not spread to the wider response to this disaster, though efforts are underway to potentially expand this type of Sea Grant–FEMA partnership for future fishery community disasters. Nevertheless, general assistance for ecosystem response and recovery actions is not planned for or foreseen in these laws in any comprehensive way. Future reauthorizations of these laws need to address this shortcoming and include appropriations for an emergency fund to plan for and respond to ecosystem damage from natural and man-made disasters, as well as to better assist those individuals and businesses that make their living from sustainable uses of natural resources and ecosystems.

Ecosystem specialists can advocate for the importance of considering ecosystems directly to on-the-ground emergency managers, through their own chain of command as in the Sea Grant example above, as well as to legislators, students, and the community and through environmentally concerned nongovernmental organizations and lobbying groups. They can also help in the process of valuing specific ecosystem goods and services. Emergency managers can recognize the important link between ecosystem health and the recovery and economy of communities. They can also invite ecosystem specialists to participate in emergency management planning and response.

Other important policy and procedures in regards to emergency management include the establishment of the National Incident Management System (NIMS) in 2004 (U.S. Department of Homeland Security 2004a) as a result of Homeland Security Presidential Directive #5 (HSPD5). The NIMS provides a comprehensive and consistent approach to all-hazard incident management at all jurisdiction levels and across all emergency management disciplines. Its main components are the on-scene Incident Command System, multiagency coordination, public information, incident preparedness, and resource management, communication, technology, and maintenance systems. Under this system, the organizational structure of response personnel into operations, planning, and other departments is laid out in great detail. Many categories of potential responders are defined and even have certification processes to the point that in July 2007, FEMA released their new description of 14 job categories and classifications targeted for emergency responders who deal with domestic or captive animals. Yet, there is no such guidance for or mention of ecosystem specialists under NIMS. Ecosystem specialists and emergency managers can advocate for the inclusion and necessary training of experienced ecosystem specialists in NIMS and other disaster planning.

An all-hazard national response plan was also established under HSPD5 and was first published in December 2004 (U.S. Department of Homeland Security 2004b). The national response plan includes emergency support functions (ESF) documents that describe in detail the roles and responsibilities of federal departments and agencies and the American Red Cross as ESF coordinators or as primary or support agencies for specific subsets of emergency management response operations. The most relevant ESF for ecosystems is number 11: agriculture and natural resources. The purposes of ESF 11 are the (1) provision of human nutrition assistance, (2) control and eradication of an outbreak of contagious or economically devastating animal/zoonotic or plant disease or plant pest infestation, (3) assurance of food safety and food security, and (4) protection of natural and cultural resources and historic resources prior to, during, and/or after an Incident of National Significance. The Department of Agriculture is the coordinating agency for ESF 11. While natural resources are recognized in the plan, they are clearly a minor factor as one of a set of issues focused more on topics with traditionally measurable economic impacts. The nexus with the food and nutrition purposes of ESF 11 are likely a reason for the seafood safety assessment by Hom et al. (2008) and the fishery rehabilitation work of Gaude et al. (2008), both described elsewhere in this volume. We believe environmental professionals need to become more involved in advocating for a greater role for natural resources with less direct links to the food supply in these plans. They should also petition for funding to carry out these plans, commensurate with the true value of their ecosystem goods and services. Local emergency operations plans are supposed to transition to have the same format as the national response plan so environmental professionals can also get involved in making sure their city, county, and/or state government plans also include natural resources issues. Emergency managers at all levels should facilitate involvement of ecosystem specialists (see also Glavovic 2008, this volume).

Environmental specialists should encourage federal, state, and local natural resource trust agencies to develop all-hazard disaster response programs. Currently, because of legislative mandates, excellent programs for oil spills and shipwrecks occur, but programs for other sorts of disasters are less well developed. Emergency managers can help in this process and direct agencies and staff to potential sources of funding for such work.

Planning Details

We also want to emphasize the need for planning for natural resource issues in disaster preparedness. It is widely known that response, restoration, and mitigation efforts are most effective when there is a priori planning for training, equipment, methods, funding, personnel, and local involvement (ONHW 2006). In our own tsunami experience, we had no personnel pretrained in the necessary relevant techniques and we had to work ad hoc, decreasing our effectiveness and risking more personal injury than needed, though luckily we had no major problems. This issue is of course largely self-evident, but we do want to comment on the standard plans for natural disasters and encourage ecosystem specialists to get involved in this process at the local and state levels. In regards to tsunamis, the National Oceanic and Atmospheric Administration's (NOAA) National Tsunami Hazard Mitigation Program has recently expanded from the original five western states to include the coastal states on the East and Gulf coasts. New funding is available to these states to prepare mitigation plans that include tsunamis, and this provides an opportunity for ecosystem specialists to get involved.

Currently in the United States, mitigation plans are required of all states by the Disaster Mitigation Act of 2000, but these plans do not have to include natural resource issues per se. In Thailand, there were no prepared plans and little contact with the local community in the immediate aftermath as the government appeared overwhelmed with the humanitarian response, which was on a scale far larger than ever experienced before. Coral-List and the Conservation Science Network of the SEI, mentioned above, proved invaluable in mobilizing expert knowledge. Similar networks of resource experts could be organized at local, state, or national levels by natural resource agencies or professional societies, based on key ecosystems in those areas, to quickly mobilize as a source of ready planning knowledge and for response personnel and expertise after an event. Ecosystem specialists should join or help create such networks, and emergency managers should involve them in their activities.

Creating preparedness plans on relevant spatial and temporal scales is also imperative. In our own experience, areas differed tremendously in ways that affected all aspects of response and recovery operations. These differences need to be considered in natural resource response plans in the same way each community needs to assess its vulnerability and resilience individually to natural hazards (ONHW 2006). Here, we will briefly share a comparison of Khao Lak and Phi Phi islands in Thailand to give a sense of the issue. Khao Lak is a 24-km (15 mi) open coastline with high wave exposure and long, sandy beaches of shallow slope with underwater visibility generally less than 1 m (3 ft). Coral development is largely limited to intermittent rock outcrops and headlands. There is no boat harbor nearby. There is a narrow band of small-scale bungalow resort areas and fishing villages nestled between the beach and higher elevation national park lands further inland. The main Phi Phi island where most of our work took place is a roughly "H"-shaped island with narrow, deep bays extending out for a few hundred meters on either side of a sandy isthmus, with the main arms of the "H" being mountains of a few hundred meters elevation. As a result of this physical protection from the open ocean, waves are small and underwater visibility is high during the dry season. Coral reef development is excellent along the rims of the bays. Boat anchorage is readily available and most of the bay is accessible to swimmers and divers. Development is dense with a mix of small and large resorts.

Ideal debris removal techniques varied greatly by location. In the Phi Phi islands, all debris could be identified visually from a distance, the affected areas were relatively small, so surveys could be quicker and with wider spacing, and debris was more concentrated than in Khao Lak. In Khao Lak, we used a targeted search based on the known directions of the wave currents, the density of construction material in different areas before the wave, and knowledge of local bathymetry to find likely areas where debris concentrations settled or aggregated. In the Phi Phi islands, we could use large nets as fold-up garbage bags for scuba divers to gather smaller debris, which could then be airlifted to the surface where snorkelers or shore-based personnel with long ropes could haul in the debris to a large nearshore temporary dump (Figure 2). Larger debris was removed with large airbags or barges with cranes. Sediment resuspension was an issue inside the bay when removing large objects embedded in the sand so a suction dredge was built (Figure 3) and methods were adapted to minimize disturbance when prioritizing and removing debris. Debris operations in Khao Lak were mostly small, boat-based, and revolved around scuba divers using lift bags and boat-based personnel assisting with lifting heavy objects. Sediment resuspension was not an issue. Because of the more widely scattered nature of the debris and the smaller workforce, there was more prioritization of objects based on their perceived threat to the marine environment or humans. We solicited hotels fronting concentrations of debris to contribute to the effort.

Ecosystem specialists will be vital in helping emergency managers understand the spatial scales relevant to particular disasters. This is also true for the temporal scales of the recovery of ecosystems, which can span from days or weeks to decades, much like social aspects of disasters. Emergency managers should solicit detailed information on ecosystem impacts of high priority disasters.

Another aspect of preparedness is procuring the necessary funding and equipment for emergency response. In our tsunami experience, there was little funding or equipment in place. For several ecological projects, the TRAF was the only funding for several months and lack of funding prevented other key projects from starting. We were able to secure donations of lift bags, epoxy cement, and various boat- and dredge-related equipment, but the

Figure 2. Large pile of debris removed from the ocean in Ton Sai Bay, Phi Phi Islands. April 2005. Photo courtesy of Deborah Brosnan.

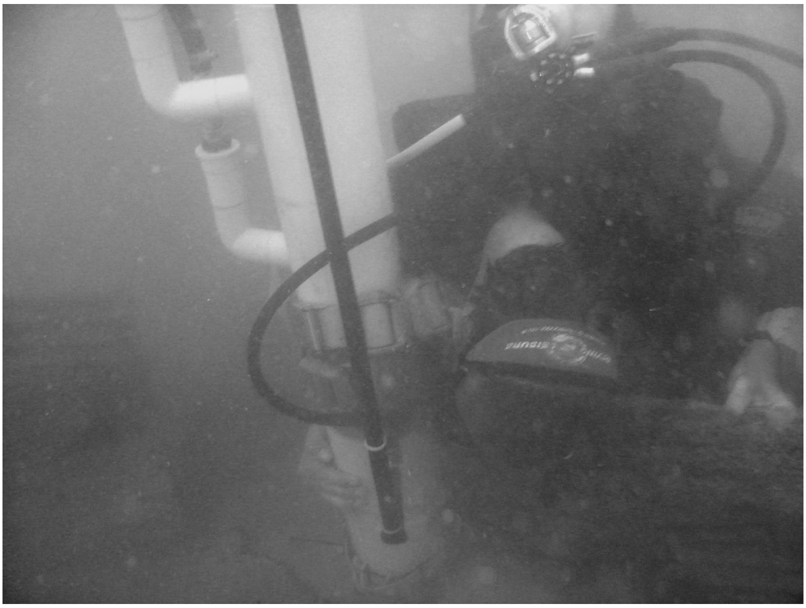

Figure 3. Suction dredge developed by the Phi Phi dive camp team. Photo courtesy of Andrew Hewitt.

acquisition process was piecemeal, required time that could have been spent on response functions, and was generally insufficient to meet all of our needs because of lack of sufficient funding. Of course, most funding for disaster response and recovery actions comes after the event. In the days and weeks after the tsunami, the government and private sector donors concentrated on funding humanitarian needs and only later began to fund ecosystem-related efforts like ours when it was clear that they had available funds. In those early days, local leaders working on ecosystem recovery projects cannibalized and adapted many types of objects to serve as lifting devices, markers, and so forth. In addition to the emergency fund called for above, ecosystem specialists should help organize themselves from the bottom up in their own communities to provide and organize the resources necessary for local responses, and NOAA and the Department of the Interior need to obtain funding for, and be more proactive in, preparing for ecosystem responses. The emergency relief fund set up by the American Fisheries Society after the 2005 hurricane season is one model of what can be done in this regard (Heitman and Jackson 2008).

While there is a good selection of published and gray literature now on survey methods and results assessing the impacts of the tsunami, there is little on coral restoration methods for situations beyond traditional ship strikes or oil spills. Reef restoration after natural disasters requires special attention to issues generally not seen in such restorations, including dealing with the larger scale of damage, more smothering of substrates by sediment and debris (Wilkinson et al. 2006), net entanglement issues for people and animals, explosive military ordnance identification and handling, and handling and disposition of victims' body parts and personal belongings. In Phi Phi, three long-term Dive Camp staff, including foreigners, were trained in police procedures so that they could properly handle and maintain chain of custody for human remains that were found while doing our work. We learned many useful lessons for training, preparedness, restoration methodology, and communication during natural disaster responses from our experiences. Some of these are discussed elsewhere in this chapter, but this material is extensive and not really appropriate for this more general policy paper. These more specific lessons can be found in Brosnan (2005) and on the Tsunami Reef Action Fund Web site (tsunamireefactionfund.org). Moreover, while there are libraries of resources for ecological restoration out there (Precht 2006; NOAA Damage Assessment, Remediation and Restoration Program Web site http://www.darrp.noaa.gov/about/index.html; The Global Restoration Network Web site http://www.globalrestorationnetwork.org), the focus for these is narrower than needed for natural disaster planning and initial response. What is really needed is an online reference library for methods related to natural resource emergency response.

Response Phase

When we first responded to the tsunami, there was much listserve traffic on Coral-List and other Internet sites regarding how to survey damages, coral restoration methods, response needs, and ideas for use of artificial reefs, as there were few documents readily available. Standard methodologies were not adopted. Much time was wasted planning and preparing, and results of different studies are not comparable. Yet the sort of damage experienced was previously known from other tsunami and hurricane events. In contrast, physical scientists are much more prepared for these kinds of events. They have standard protocols that are established for surveys after earthquake and tsunami events, teams of people are organized ahead of time to respond, and there is funding to do so. The Learning From Earthquakes program was started by the Earthquake Engineering Research Institute in 1973 and is funded in part by the National Science Foundation. There is also an International Tsunami Survey Team. In Hawaii, there is even a group of volunteer specialists who go to predetermined, safe locations with preprepared kits of equipment in order to observe and measure the arrival and immediate aftermath of a tsunami. Standardized ecosystem damage assessment surveys need to be developed that detail the status of the ecosystem resources as well as consider new or developing threats to the resources (e.g., leaking pollutants, breakdown of sewage treatment systems that will lead to ecosystems stresses, etc). Ecosystem specialists and emergency managers can each contribute to the development of such assessment programs. The Specialized Marine Action Assessment Response Team model developed for the boating and fishing community and described elsewhere in this volume (Spranger and Jackson 2008) is an excellent model for assessments of human communities that are tightly linked to marine natural resources.

Natural resource managers and biologists often lament the lack of funding to accomplish needed work but often overlook the value of volunteers. The Thai government's response was small in the area of ecosystems because of a lack of funding and probably a lack of understanding of the importance of ecosystem goods and services. However, there was a ready pool of volunteer organizations and individuals interested in the health of the marine environment. On Phi Phi Island, Andrew Hewitt utilized his familiarity with the local area, his skills as a diver and former construction worker, and his business and marketing acumen to quickly get the word out about efforts and opportunities to help the marine environment of his local community. He started the Phi Phi Dive Camp and secured financial and in-kind support to pay for Thai people to be employed in the program and volunteers to be freely housed and fed. Since the Phi Phi islands have been a famous "backpackers" tourist destination for years, a large pool of well-to-do foreigners donated and traveled to the area to help the islands. D.B. worked closely with PROJECT AWARE to identify and link volunteer scuba divers with projects such as Phi Phi Dive Camp. Hewitt did an excellent job of getting the most out of all available labor, including scuba divers, snorkelers, and those who could only help onshore. His program ran full-time for 10 months, and for 4–5 months, he was using about 80 volunteers a day. He quickly developed qualifications and training protocols to take advantage of the labor. But a lot of his efforts were trial and error and were held back initially by the lack of appropriate equipment and training. In Khao Lak, Stuart Robbens became the environmental coordinator at the Tsunami Volunteer Center (TVC), another organization that spontaneously developed in the tsunami aftermath to help in the Khao Lak area. This organization took on a wide variety of tasks from providing food, water, shelter, and morgue services immediately following the tsunami to home and boat construction and skills development for survivors in the areas of arts and crafts, languages, and furniture making in the recovery phase of the disaster. In Robbens' case, he benefited from the word-of-mouth and media attention that brought folks to the TVC, but he also had to compete for volunteers working in these other areas, and ecosystem projects were often prioritized lower for assigning volunteers within the organization.

These examples show that, after natural disasters, there will often be a ready pool of labor available to help. Government at all levels could do a better job of training, equipping, and involving volunteers to help after such disasters. There is at least one established program that hints at what is possible. In the Florida Keys National Marine Sanctuary, a Reef Medics program was started in 2002 to train and use volunteer snorkelers and scuba divers to assist in identifying damage to corals from ship strikes. In some cases, the volunteers are trained in reef restoration methods as well. This is a good model for a program that could be more widely developed by ecosystem specialists to include training in skills necessary to respond to disasters, as well as other events damaging to ecosystems like major runoff events. In many areas, there are already existing networks of volunteers trained and active in reef monitoring programs through groups such as Reef Environmental Education Foundation and Reef-Check, and these organizations also could expand their mission and partner with governments to provide a cadre of ecosystem first responders. Even if these volunteers were only trained in the preliminary triage skills of turning over and stabilizing corals overturned by the waves, a significant amount of living reef habitat could be saved that would otherwise quickly die.

Recovery Phase

There should be protocols in place to prioritize what types of habitat and what types of interventions will be considered in the recovery phase. Factors that should be considered include not only benefits to ecosystem goods and services, but also the traditional economic benefit, the need to enhance natural recovery and the chance of success, and the available personnel, funding, and expertise. A good deal of time was used in the aftermath of the 2004 tsunami deciding what was the most important priority for work and in finding appropriate methods and expertise. However, we had a collaborative group that worked well together and never lost sight of the ultimate goal, which helped ensure that what was done was useful. Moreover, a wide holistic view that includes all stakeholders and all resources is needed in these situations so that all implications are considered. For example, we encouraged a higher prioritization of efforts for our partners working on land to clear stream channels and nearby riparian zones of debris. Initial clean-up efforts were focused only on residential and beach areas in addition to the underwater cleanups. But we realized that when the rainy season began that new debris would be washed into the marine environment unless debris was removed from stream channels. This would undermine the underwater efforts and move potentially dangerous debris back into tourist areas where economic impacts and later removal costs would be greater. We also partnered with other groups on land to help prioritize revegetation efforts that would minimize further degradation of nearshore areas where we worked.

Most of the methods for restoration of coral reefs in the recovery phase are documented in Precht (2006) so we do not delve deeply into them here. The main area where we learned new lessons was in the specific details of Annella seafan restoration described above. Those lessons are too detailed for this policy paper but can be found in Brosnan

(2005), in Petchrung (2006), and in reports at tsunamireefactionfund.org.

We do want to advocate for more funding for development and research into new and improved restoration methods. Currently, there are few resources in this area, and legal constraints in dealing with shipwrecks and oil spills prevent much experimentation, though new provisions in the reauthorization of the Coral Reef Conservation Act being considered by Congress may decrease this problem for reef restoration. However, there are several promising new techniques for coral nurseries, use of electric currents to speed coral calcification and the raising of coral propagules in the laboratory for field transplantation (Precht 2006), that should be encouraged. One of our Thai partners in the coral restoration efforts, the governmental Phuket Marine Biological Laboratory, has developed a coral nursery program in the Phi Phi islands in coordination with the Phi Phi Dive Camp and some of the other techniques listed above were used for response to the tsunami by other responders. Ecosystem specialists should consider applying their research skills to these questions as the impacts to ecosystems from disasters can be so great. All can encourage policy makers to fund increased efforts in this area.

Recovery plans often contain provisions for the implementation of new laws to deal with the recovery process, such as new zoning laws, temporary building permits, and other provisions. An area for consideration by ecosystem specialists in these plans is new or altered regulations on take of or disturbance to marine organisms and habitat. For instance, after the tsunami, certain islands in the Similan Islands National Park were rezoned to prevent tourism until the reef resources could recover. After the 2005 hurricanes, the consultation provisions of the Endangered Species Act were lifted for construction to restore infrastructure to its original footprint. Ecosystem specialists can help emergency managers prepare for such potential effects of disasters.

Another challenge in the recovery phase is monitoring the progress and success of recovery actions. This should not be overlooked when planning and seeking funds for recovery actions. The network of experts that we suggested be developed in the preparedness section (above) will be useful here.

Mitigation Phase

Mitigation efforts, in the emergency management sense of the term, are possible to lessen the impact of future tsunamis to reef environments. The need for proper planning and an emergency fund has already been mentioned. Another area where ecosystem specialists can contribute is in the land use planning arena at the state or local levels. Land-use plans can have many features that impact natural resources, and they also lay the groundwork for what issues will have to be dealt with around natural disasters. Ecosystem specialists should be part of the land-use planning process to point out implications for ecosystems from current or proposed plans, especially in light of potential disaster scenarios. One common feature of land use plans that is relevant to aquatic ecosystems that we wish to highlight is shoreline setbacks. Large shoreline setbacks are usually considered a method to protect property from coastal erosion or even storm surge. After the tsunami, larger shoreline setbacks were instituted in parts of Thailand and Sri Lanka to protect people in some vulnerable areas by prohibiting development close to the shore, giving people more time and an easier escape route for future tsunamis. Such setbacks may also serve to decrease the amount of debris that will potentially end up in the ocean and this may be a valuable goal in some areas to prevent ecosystem damage. While many areas currently have small shoreline setbacks, having recovery plans in place that establish revised setbacks changes to be enforced after a tsunami or hurricane storm surge flood event can mitigate for the next disaster (ONHW 2006). Since most land-use plans are also not regulatory, vigilance is needed to ensure that features that help protect natural ecosystems are implemented as planned.

Attention to zoning laws that determine what sorts and densities of construction can occur in specific areas is another focus for potential mitigation efforts. Usually this topic is considered by emergency managers in the context of siting or moving critical facilities like hospitals, utility plants, and so forth outside of hazard zones. Ecosystem specialists can play a role in these decisions by advocating for prohibitions on siting or requirements for safeguards for facilities in inundation zones that contain large amounts of materials that if released by a tsunami or hurricane storm surge event would cause excessive damage to marine ecosystems. Examples include petroleum tank farms or the military weaponry lost at sea from the Thai naval base adjacent to Khao Lak.

Smaller scale mitigation measures are also applicable in this realm. For instance, a scuba recompression chamber doctor who returned to Khao Lak immediately after the tsunami was consumed with worry that he had caused injury or death by failing to secure a large cylinder of compressed oxygen to the outside wall of his business. This is much like the methods for earthquake proofing homes that are now widespread in at-risk areas. Requiring adequate containment and security of dangerous items in tsunami inundation zones is another regulatory change and common sense protection that those concerned with environmental effects of natural disasters need to advocate for.

Likewise, construction standards for engineering buildings to withstand tsunami forces have been adopted in some places, including Hawaii, and are being revised based on lessons learned from the 2004 tsunami. Closer attention should be paid, not only to engineering standards, but also changes to building codes about types of material used in coastal zone construction that would decrease the impact if such material were to end up in the ocean after a hurricane or tsunami. For example, more biodegradable or inert materials could be required.

Education is also a mitigation measure, and the natural resources community needs to do a better job of educating various sectors of the public and decision makers about the value of ecosystem goods and services, the necessity to protect and restore natural resources damaged by disasters, and the methods and plans of natural resources response and recovery actions. Emergency managers can make all types of mitigation and preparation education a high priority.

Conclusion

The great human and natural environmental tragedy that occurred on 26 December 2004 has spurred many improvements in warning systems, preparedness plans, education, and response and recovery methods and coordination. In the realm of natural resources, there has been a greater appreciation for the protective benefits reef and mangrove ecosystems can provide. We have tried to summarize our broader policy lessons learned for the benefits of responding to natural disasters, encouraging the general public and ecosystem specialists to speak the language of and become more involved in the emergency management disaster cycle, and advocating for emergency managers to solicit more participation from the natural resources community. Much of this work will require greater funding and time commitment by a variety of specialists. We have refrained from providing proscriptive steps for involvement because we anticipate that a wide variety of readers, from aquatic ecologists or restoration specialists to natural resource managers as well as experts in the various components of emergency management, will read this article. Each specialty will bring different skills and interests and will be able to contribute to certain tasks and phases of the disaster cycle. Moreover, emergency management responses and planning start at the local level and higher levels of government only become involved when lower levels are overwhelmed by larger scale disasters. While the framework of emergency management response is now much more uniform across government levels, there are still tremendous differences at each of these levels, even within the United States. We chose to focus on the national level for this paper, which enabled us to give specific examples without overwhelming the reader with details regarding all levels of government. The level and detail in which one can get involved varies tremendously. But all should contribute in some way because of the enormous impact such acute events can have. We hope those who plan for and respond to the next disaster will benefit from our thoughts.

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