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Black Swans, Wicked Problems, and Science During Crises

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INTRODUCTION

Oceanic resources face challenges that are significant and widespread, including (but not limited to) overharvesting, climate change, selected stock collapse, coral reef decline, species extinction, pollution, and more. These challenges are the focus of much ocean science, which is helping to inform policy and guide management actions. The steady growth of research results and the emergence of new research needs have been systematically reviewed through periodic assessments, such as those of the Intergovernmental Oceanographic Commission (Valdés et al., 2010).

Yet, oceanic resources are also at risk due to specific *crisis events*—temporally and spatially explicit incidents that are both human emergencies and potential environmental disasters. Examples include the *Exxon Valdez* oil spill in Alaska (1989), the *Prestige* oil spill off the Finnesterre coast of Spain (2002), the Indian Ocean tsunami (2004), the Jabel al-Zayt oil platform spill in the Red Sea (2010), and the radioactivity leak at the Fukushima Dai-ichi nuclear complex in Japan (2011). These crisis events have resulted in new scientific findings; examples are the Spanish and international scientific response to the *Prestige* event (Albaigés and Morales-Nin, 2006) and ecological research accumulated after the 1979 Ixtoc I oil spill in Mexico's Bay of Compeche (Teal and Howarth, 1984). However, there is a critical need to develop organizing structures, methodologies, and delivery tools for conducting science *during* environmental crises.

The need for science during crisis is not restricted to ocean-related events, and there are numerous historical examples of science conducted under emergency conditions. Examples include the British research effort to develop a workable radar system prior to the air war over England, the activity of the Research and Analysis Branch of the Office of Strategic Services (OSS) during World War II, the Manhattan Project to develop the atomic bomb, the engagement of scientists and engineers during the Apollo 13 emergency return to Earth in 1970, and the work of epidemiologists and disease specialists during the initial 1976 outbreak of the *Ebola* virus in Zaire. Another (and more recent) example is the response to the 2010 Deepwater Horizon oil spill. The lessons learned from the Deepwater Horizon oil spill suggest that planning for science during crisis is both essential for informed decision making, and valuable for mid-term and long-term recovery efforts. Such planning can also improve early warning monitoring and crisis preparations.

STRATEGIC SCIENCE FOR THE DEEPWATER HORIZON OIL SPILL

The Deepwater Horizon oil spill began with the platform explosion on April 20, 2010. Within days, the technical complexity of ending the spill and the potential gravity of the environmental impacts became apparent. Scientific activity quickly began, ranging from flow estimation work of the Flow Rate Technical Group, to inventory and monitoring in support of the Natural Resource Damage Assessment (NRDA) process, and agency-specific tasks such as Environmental Protection Agency (EPA) toxicity studies, to a broad (and uncoordinated) array of local and national nongovernmental organization (NGO) and university research expeditions to the Gulf of Mexico.

Much of this research was

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tactical—documenting pre-spill conditions, monitoring oil transport, assessing damage to resources, and supporting technical decisions necessary for containing the oil. This research was also largely discipline focused. Interdisciplinary science specific to the near- and long-term consequences of the Deepwater Horizon oil spill was not readily available, yet such *strategic* science was essential to support decision making regarding near- to long-term recovery.

While the spill continued to resist an engineered kill, the US Department of the Interior (DOI) established an experimental Strategic Sciences Working Group (SSWG). SSWG's mission was to rapidly develop science-based scenarios related to the Deepwater Horizon oil spill, focusing on the impact of the spill on the ecology, economy, and people of the Gulf of Mexico. SSWG included federal scientists, NGO researchers, and local university faculty. Working group participants came from a wide variety of relevant disciplines (oceanography and marine toxicology were represented) and brought to the group their particular disciplinary expertise, interdisciplinary skills, and experience with crisis events. Many had extensive experience with oil spills and/or Gulf of Mexico systems. SSWG met in Mobile, Alabama, and New Orleans, Louisiana, during May and again in July 2010, developed five detailed scenarios, and periodically briefed DOI leadership and other decision makers.

SSWG used a scenario-building technique adapted for the crisis. The technique involved using a specific coupled human-natural systems model to identify key variables, and then applying a scenario framework that allowed for scenario building with varied parameters and assumptions such as flow rate, days to containment, and frequency of future tropical storms and hurricanes. For each of the potential cascading effects, a level of uncertainty was assigned following a standardized protocol. For some of the cascading effects, potential interventions that could accelerate a sustainable recovery or prevent additional system stress were identified. A detailed description of the methodology and results is available (see Machlis and McNutt, 2010; DOI, 2010).

The scenarios developed by SSWG helped reveal the complexity of potential cascading effects and the alternative resilience and recovery trajectories for the region affected by the Deepwater Horizon oil spill. Uncertainty estimates provided a "road map" for prioritizing future research. Most importantly, scenario briefings during the crisis provided DOI leadership with strategic insights that could be combined with other policy, legal, and economic inputs—all helping to inform decision making. Efforts are now underway to take the lessons learned from SSWG and apply them to future environmental crises.

INCREASING THE CAPACITY FOR STRATEGIC SCIENCE DURING CRISIS

Government agencies from local to federal face a range of potential crisis events, including wildfires, hurricanes, dam failures, droughts, oil spills, earthquakes, and bioterrorism attacks. For those with ocean resource responsibilities, future crises might also include extraordinary but plausible events such as multiple oil platform failures, ocean piracy combined with toxic releases, and atmospheric river "ARkStorm" mega storms (as recently examined by Porter et al., 2011). Some of these crises may be what Taleb (2007) describes as *black swans*—events that are rare, extreme in impact, and difficult to predict. Others may be environmental *wicked problems* (Balint et al., 2010)—relatively widespread, highly complex and uncertain, and reasonably predictable. In both cases, a standing capacity for conducting


US Department of the Interior Strategic Sciences Working Group, New Orleans, LA, July 2010. *Photo credit: Jason Newman*

strategic science during crises can be vital to effective response.

Developing an effective strategic science capacity for crisis events (including events impacting oceanic resources) requires three key actions. The first is to create organizational structures capable of rapidly mobilizing the scientific community. Such structures should maximize flexibility and responsiveness, and avoid unnecessary bureaucracy. Rosters of scientists trained in strategic science and ready to serve must be created and maintained, not unlike the systems in place to staff incident commands for forest fires within federal land management agencies. Training in scenario building and uncertainty assessments should be routine and extensive, with operational group leaders well prepared for leading crisis science teams. A reasonable set of goals is for an organizational structure capable of handling two different, disparate, and distant crisis events simultaneously (e.g., an East Coast oil spill and a Pacific Northwest earthquake), a strategic sciences operational group to be in the field and working within 24 to 36 hours of deployment, and delivery of science-based scenarios to decision makers within 48 hours.

Second, the methodologies and techniques for developing crisis scenarios must be continually improved. Although the Deepwater Horizon scenarios had some temporal and spatial specificity, refinement in technique could result in more detailed results. Qualitative techniques can form the foundation for more quantitative methods. The development of uncertainty assessments can be further improved, and risk analysis can be added to help prioritize critical scenarios. These methodological improvements can best be accomplished by scenario work during noncrisis periods, focused on predictable but complex problems, such as Arctic oil spills or western US wildfires. These trials can also contribute to development of safety practices, early-warning monitoring, and improved emergency preparations. In addition, there is a need to develop methods to conduct "actionable peer reviews"—systematic scientific review of technical issues that emerge during crisis events. Such reviews should engage the wide community of scientific expertise on an issue and deliver to decision makers the results of the reviews quickly, often measured in hours. Cloud computing, advanced Delphi techniques, and sociometric analyses could be combined into useful and practical tools.

Third, effective strategic science is science well delivered to decision makers. It must be concise, convincing, and compelling. It must communicate both the essential findings and their uncertainties, and provide both objective information and balanced insight. Advances in visualization techniques from other fields (such as avionics, gaming, and biotechnology) should be applied to create tools of communication necessary for strategic science to deliver usable knowledge while a crisis event is underway.

Strategic science during crisis events is not a substitute for traditional research and its cumulative progress. The black swans and wicked problems of the near future require the continuous advance of our understanding of complex systems, including the world's ocean. Yet, it is also vital that the scientific community anticipate black swans and wicked problems, and prepare for science during crisis.

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