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Special Section

Designing Climate-Smart Conservation: Guidance and Case Studies

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Abstract: *To be successful, conservation practitioners and resource managers must fully integrate the effects of climate change into all planning projects. Some conservation practitioners are beginning to develop, test, and implement new approaches that are designed to deal with climate change. We devised four basic tenets that are essential in climate-change adaptation for conservation: protect adequate and appropriate space, reduce nonclimate stresses, use adaptive management to implement and test climate-change adaptation strategies, and work to reduce the rate and extent of climate change to reduce overall risk. To illustrate how this approach applies in the real world, we explored case studies of coral reefs in the Florida Keys; mangrove forests in Fiji, Tanzania, and Cameroon; sea-level rise and sea turtles in the Caribbean; tigers in the Sundarbans of India; and national planning in Madagascar. Through implementation of these tenets conservation efforts in each of these regions can be made more robust in the face of climate change. Although these approaches require reconsidering some traditional approaches to conservation, this new paradigm is technologically, economically, and intellectually feasible.*

Keywords: adaptation, adaptive management, climate change, coral reef, mangrove forest, resilience, sea turtle, tiger

Diseño de Conservación Considerando el Clima: Directrices y Estudios de Caso

Resumen: *Para ser exitosos, los practicantes de la conservación y los manejadores de recursos deben integrar los efectos del cambio climático en todos los proyectos de planificación. Algunos practicantes de la conservación están empezando a desarrollar, probar e implementar nuevos métodos diseñados para hacer frente al cambio climático. Diseñamos cuatro preceptos básicos esenciales para la adaptar la conservación al cambio climático: proteger espacios adecuados y apropiados, reducir los estreses no climáticos, utilizar manejo adaptativo para implementar y probar estrategias de adaptación al cambio climático y trabajar para reducir la tasa y extensión del cambio climático para reducir el riesgo global. Para ilustrar la aplicación de este enfoque en el mundo real, exploramos estudios de caso de arrecifes de coral en los Cayos de Florida; manglares en Fiji, Tanzania y Camerún; elevación del nivel del mar y tortugas marinas en el Caribe; Tigres en Sundarbans, India y la planificación nacional en Madagascar. Mediante la implementación de estos preceptos, los esfuerzos de conservación en cada una de estas regiones pueden ser más robustos a la luz del cambio climático. Aunque estos enfoques requieren la reconsideración de algunos métodos tradicionales de conservación, este nuevo paradigma es factible tecnológica, económica e intelectualmente.*

Palabras Clave: adaptación, arrecife de coral, cambio climático, manejo adaptativo, manglar, resiliencia, tigre, tortuga marina

Introduction

Climate change is a fact of our times (IPCC 2007). It is already altering ecosystems from the poles to the tropics (Root et al. 2005; Parmesan 2006) and will do so for decades or centuries to come. This change is happening faster than originally expected (IPCC 2007; Feely et al. 2008) and faster than most managed systems have

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experienced previously (Barnosky et al. 2003). Conservation must adapt to deal with this new reality.

The current conservation paradigm is largely predicated on static spatial planning, including establishment of protected areas and corridors of connectivity, and designation of important habitat. Identification and prioritization of conservation areas are based on current conditions, ranges, and environmental parameters; however, climate change is turning ecosystems previously viewed as stable—at least on the scale of conservation planning—into rapidly changing landscapes and seascapes. Approaches to conservation need to move from a conservation paradigm dominated largely by static spatial constraints to one that incorporates temporal shifts in ecosystems and species and other extra-spatial influences.

Tenets of Climate-Smart Conservation

To maintain or increase resistance and resilience of systems to climate change and thus create climate-smart conservation, four basic tenets should be considered: protect adequate and appropriate space, reduce nonclimate stresses, apply adaptive management to implement and test adaptation strategies immediately, and reduce the rate and extent of climate change to reduce overall risk to the conservation unit of concern. There are a number of frameworks for maintaining or increasing resilience of systems to climate change that have been put forward, and each has its own set of approaches. Our goal here is not to create the definitive framework, but to present a framework that is simple, comprehensive, and allows practitioners to easily build on it in ways that make sense for the system or species with which they are concerned.

Protect Space

Protected-area design can address the probable effects of climate change in a host of ways. For example, conservation plans can protect climate refugia (areas expected to experience relatively smaller changes in climatic conditions); create corridors or networks of reserves that allow species and organisms to move with changing conditions, particularly along gradients (elevational, longitudinal, bathymetric, or climatological); protect networks that allow for gene flow and population connectivity; protect or restore features such as forests that contribute strongly to local climatic conditions; protect more-resilient populations; and protect heterogeneity of habitat, communities, and species (Hansen et al. 2003; West & Salm 2003; Millar et al. 2007). The overarching goals are to support natural processes, places, and features that minimize or mitigate effects of climate change and, where possible, to create replicate reserves for each species or habitat of concern to guard against unanticipated changes. Practitioners and managers can work to determine what constitutes adequate and appropriate space for their particular region by considering past, present, and future effects of climate change on their region as a whole and on the species that are particularly important in shaping local ecosystems (keystone predators and ecosystem engineers).

Reduce Nonclimate Stresses

Climate change is not a lone stress on the systems of our natural world; rather, it occurs in concert with a host of other stresses (e.g., habitat degradation and destruction, overharvest, pollution, invasive species). Generally, already stressed ecosystems and organisms are less resilient to climate-change effects. Further compounding the problem is that many stressors interact synergistically with climate change, in particular increasing temperature, altered hydrological regimes, and altered environmental chemistry (e.g., ocean acidification). Myriad examples in the toxicological literature demonstrate that such environmental changes affect the toxicity threshold of various environmental pollutants (Mc Lusky et al. 1986; Ficke et al. 2007). There are analogous studies in the invasive species literature (Dukes & Mooney 1999; Mooney & Hobbs 2000), disease literature (Patz et al. 1996; Harvell et al. 2002; Mueller et al. 2008), and overharvest literature (Finney et al. 2000). Acceptable or manageable levels of these stresses need to be recalibrated, and management and regulatory structures need to take into account that the impact of these stresses will likely be greater than anticipated when the effects of climate change are factored in. One cannot simply set new standards, however; standards must be devised that will be responsive to the ever-changing environment brought about by climate change.

Adopt Adaptive Management

Adaptive management is an “integration of design, management, and monitoring to systematically test assumptions in order to adapt and learn” (Salafsky et al. 2002). With time of the essence, years cannot be spent developing adaptation strategies and redesigning conservation efforts to make them climate adaptive; adaptation is a bicycle we must build while we ride it. Where possible, implementation and testing of new approaches to conservation and management must occur simultaneously. This includes creative measures that can ameliorate the effects of climate change and modifications of more traditional approaches. Adaptive management, which runs on a cycle of implement–monitor–evaluate–adjust, provides

Table 1. How the four tenets of climate change conservation are applied in the conservation plans of five case studies.*

Case study	*Adequate and appropriate space*	*Reduce nonclimate stresses*	*Adopt adaptive management*	*Reduce rate and extent of climate change*
Florida Keys	use relationships between water-quality patterns and coral resilience to provide new spatial framework for resource management	determine relationships between regional water quality patterns and coral bleaching to improve regulation	identify resilience patterns to help focus limited resources in conserving resilient and sensitive but valuable coral reefs	State of Florida Executive Order to reduce greenhouse gas emissions to protect Florida's resources
Mangroves	identify biophysical links between reefs and mangroves that support resilience for both ecosystems	evaluate ability of mangroves to improve water quality over reefs	identify metrics for mangrove vulnerability for on-going evaluation of resilience-building efforts	
Madagascar	qualitatively identify vulnerable and resilient marine areas to inform creation of nationwide MPA system create vulnerability index for coral ecosystems to provide quantitative data for MPA selection	build nonclimate stressors into vulnerability index for coral reefs to help target key stressors for reduction	use vulnerability index to evaluate and adjust resilience-building efforts	
Sea Turtles	identify and protect beaches more resilient to climate change protect land behind nesting beaches to allow for natural beach migration inland with sea-level rise restore and protect habitat associated with valuable beaches		measure effect of coastal vegetation restoration on nest temperatures and adjust restoration strategies as needed to maintain viable sex ratio	
Sundarbans	prioritize protection of islands or parts of islands less susceptible to sea-level rise and where wildlife–human conflict can be minimized		create GIS maps to visualize where tigers and people are and may move as sea-level rises and adjust conservation action accordingly	

**Abbreviations: MPA, marine protected areas; GIS, geographic information system.*

a framework for this sort of experimentation. There have already been large changes in Earth's climate and chemistry (IPCC 2007), and these changes are already affecting ecosystems around the world (Parmesan & Yohe 2003). In the implementation of adaptive management, one cannot lose sight of the urgency of the work. The window of opportunity for many conservation actions that could lessen the damage of climate change is in the process of closing.

Reduce the Rate and Extent of Climate Change

To reduce the effects of climate change on ecosystems, the most prudent course of action is to limit the rate and extent of climate change itself. Although this may not seem like "conservation," it is a key to the success of conservation. As the pace and extent of climate change increase, the cost of adaptation also increases while the likelihood of success decreases. Applying the precautionary principle by taking action to stop root causes may be the best way to protect those things we are trying to preserve—species, habitats, landscapes, or planets.

How these four tenets are applied will play out differently depending on ecology, regulatory framework, existing capacity, availability of baseline data, available funding, and other factors. The case studies presented here focus on marine ecosystems, but they cover a wide geographical range and focus on everything from individual species to linkages among multiple ecosystems. These case studies illustrate how this common set of resilience-building conservation tenets can be translated to suit a variety of needs (Table 1).

Florida Keys National Marine Sanctuary

The Florida Keys National Marine Sanctuary was established in 1990 to help protect and preserve nearly 1 million hectares of marine environment, and it encompasses seagrass meadows, mangrove islands, and the most extensive living coral reef in the United States. Annually over 3 million people visit the sanctuary or derive their livelihoods from its resources (Leeworthy & Wiley 1997; Leeworthy & Vanasse 1999). Climate change is already adding to the challenges the sanctuary's resource managers face. Coral bleaching in the sanctuary has been documented since the 1980s, and mass bleaching occurred in 1990, 1997, and 1998 (Causey 2001). Waters are now warm enough to induce bleaching every year (NOAA 2008), and some amount of bleaching now occurs almost annually (Tupper et al. 2008).

In 2006 the World Wildlife Fund (WWF) started to examine environmental and monitoring data in new ways to investigate the resilience of Florida's reefs to the combination of climate change and other stressors and to implement the conservation tenets described above. Using landscape ecology and geographical information system (GIS) techniques, researchers are quantifying temporal and spatial relationships between key environmental parameters and coral-bleaching response that can reveal patterns in reef resilience. Knowledge of established correlations and patterns can help conservation practitioners focus limited resources by conserving coral reefs in locations that show the greatest resilience or where reefs are sensitive but highly valuable. These efforts in the Florida Keys are only one part of the larger Florida Reef Resilience Program, which brings scientists, reef managers, and people whose livelihoods and recreational pursuits depend on healthy coral reefs together to achieve a common goal. This dynamic stakeholder process was created to increase involvement, understanding, and buy-in by participants to improve the likelihood of putting a flexible, adaptive-management approach in place. Implementation of the four tenets was made easier in this project because a range of background physical and biological data existed, stakeholders had previous involvement in planning of marine protected areas, and sanctuary personnel were willing to explore novel approaches. Parallel to this process, in 2007 the state of Florida committed to reducing greenhouse gas emissions to protect the state and its resources from the effects of climate change.

Mangrove Forests

Straddling the line between land and sea, mangrove forests are an integral part of coastal ecosystems in the tropics. They provide numerous ecosystem services, including wood for fuel and construction, coastal protection, and essential habitat for important fish and invertebrate species. In 2006 WWF began a three-country project with the goal of developing and testing a generalized framework for vulnerability assessment and adaptation planning focused on this valuable ecosystem.

One element of protecting "adequate and appropriate" space is identification of strong physical and biological connections between different habitats, and development of approaches that address linked habitats together rather than in isolation. Mangroves and coral reefs are two such tightly linked habitats. Reefs help lessen the force of waves on adjacent mangroves, and mangroves reduce stress on corals by decreasing the amount of sediment and pollution reaching reefs and releasing ultraviolet-blocking colored dissolved organic matter (CDOM) into the water (Zepp 2003; Grimsditch & Salm 2006). As part of this project, WWF is investigating whether the effects of mangroves on water quality might lessen the susceptibility of fringing reefs to bleaching. In Fiji they are also investigating the relationship between watershed health and the status of mangroves and corals influenced by that watershed.

A second key element of the project is identification of appropriate metrics for measuring mangrove vulnerability to effects of climate change. In the case of coral reefs, bleaching and recovery are well-established vulnerability metrics. For mangroves, however, there is as yet no clear set of metrics, without which active adaptive management is impossible.

Madagascar

Over the past year, WWF and Conservation International have coordinated, along with the Wildlife Conservation Society, U.S. Agency for International Development, and the government of Madagascar, a national vulnerability assessment for Madagascar's marine and terrestrial ecosystems. This assessment was developed not as an end in itself, but as a springboard for actions to reduce Madagascar's vulnerability to climate change. For simplicity's sake, we focused on coral reefs, but the process is being applied to other habitats and species.

The government of Madagascar is developing a system of marine protected areas (MPAs) but has not finalized criteria for identifying and prioritizing potential MPA sites. As part of the vulnerability assessment and to assist in site selection, data sets for multiple climatic and oceanographic variables influencing coral bleaching risk were compiled into a GIS database. These variables were combined to create and map an overall vulnerability index (Maina et al. 2008). A group of experts discussed differences between modeled vulnerability and observed bleaching and ways to improve vulnerability modeling by incorporating various biological and nonclimatic factors. In addition to delineating variation in vulnerability to bleaching, the improved model will highlight areas where nonclimate stressors, such as overexploitation or terrestrial runoff, may be significant contributors to coral bleaching. Thus, the model can inform site selection by identifying areas likely to be resistant or resilient to bleaching and protected-area management by identifying which nonclimate stressors have the biggest effect on resilience. The system is also designed to facilitate adaptive management. The model clearly lays out variables of concern and metrics for measuring changes in vulnerability as conservation measures are enacted. Additionally, the model can be refined with the addition of more variables if other factors contributing to bleaching are identified.

Sea Turtle Habitats

Sea turtles use a range of marine habitats during their life cycle, are long lived, ectothermic, highly migratory, and have temperature-dependent sex determination; all of these life-history characteristics expose them to the effects of climate change over great spatial and temporal scales. Sea turtles, are, therefore, an ideal species with which to explore and communicate the vulnerability of coastal and marine ecosystems to climate change and options for adapting to climate change (Houghton & Hays 2007).

The loss of nesting beaches due to sea-level rise is one of the greatest potential threats of climate change to sea turtles. The average rate of sea-level rise has increased from 1.8 mm/year prior to 1993 to 3.1 mm/year since then (IPCC 2007). Coastal ecosystems are particularly vulnerable if infrastructure, coastal development, or cliffs prevent the landward shift of these ecosystems as sea level rises. On the Caribbean island of Bonaire, for example, up to 30% of nesting area would be lost from a 0.5 m rise in sea level (Fish et al. 2005). Similar beach losses are anticipated for Barbados (Fish et al. 2008). In the Caribbean, 20% of historic nesting sites for sea turtles have already been lost and 50% of the remaining sites are at high risk of loss (McClenachan et al. 2006).

Successful marine turtle conservation will require that the effects of climate change, such as sea-level rise, be included in long-term planning for human development and conservation. Implementation and enforcement of adequate setback regulations creates the potential to maintain the ecological and economic function of beaches in the face of extensive coastal development and sea-level rise (Fish et al. 2008). Strategically designed setbacks (i.e., areas behind nesting beaches kept devoid of infrastructure), are likely to be more economically and ecologically sustainable than beach protection through armoring. Local estimates of beach loss from sea-level rise, derived from beach profiles and the Bruun model for beach recession, help identify the appropriate setback needs at each site and have been recommended as a management tool in Barbados, a key nesting locality for Caribbean hawksbill turtles (*Eretmochelys imbricata*) (Fish et al. 2008).

Sea turtles are also vulnerable to rising temperatures because sex is determined by incubation temperature. Nesting in areas shaded by vegetation can lower incubation temperatures and sustain production of male hatchlings (Janzen 1994). In Tortuguero, Costa Rica green turtle (*Chelonia mydas*) nests laid under vegetation produce an estimated 94% male hatchlings (Standora & Spotila 1985). The restoration or protection of native, coastal vegetation at nesting sites is a nonintrusive adaptation measure for the conservation of marine turtles that also benefits other wildlife, slows dune erosion, and maintains beach tourism. An alternative is to translocate nests laid in areas or seasons that are likely to result in thermally unsuitable conditions to cooler spots. Targeted translocation may also mitigate the risk of rising water tables from extreme rainfall events, which may also negatively affect hatchling survivorship. These intrusive measures, however, require considerable knowledge about the nesting biology and population dynamics, and should not be undertaken widely as a one-size-fits-all solution.

Sundarbans

Sea-level rise also causes problems for Bengal tigers (*Panthera tigris tigris*) and the millions of people with whom they share the Sundarbans—a region composed of mangrove islands in India and Bangladesh. This region is a World Heritage site, a wetland of international importance under the Ramsar Convention on Wetlands, and home to the largest mangrove forest in the world. It has a maximum elevation of 10 m (Gopal & Chauhan 2006) and most is far lower. The combination of global sea-level rise and other stressors will likely lead to the loss of 75% of the Sundarbans' mangroves by the end of the 21st century (Colette et al. 2007). Islands designated as protected tiger habitat and islands currently inhabited by people are being lost, which has increased tiger–human interactions and development pressure on remaining islands. Successful long-term protection of tigers in this region will require identifying potential new tiger habitat (islands that are currently relatively undeveloped) and limiting adverse tiger–human interactions. A GIS-based spatial analysis that incorporates different scenarios of sea-level rise, submeter elevation data, and current human and tiger land-use patterns is being used to identify habitat vulnerability to sea-level rise and areas where tigers and people are likely to move. This analysis can be applied to development and land-use patterns in ways that increase the likelihood that both people and tigers will continue to live in the Sundarbans.

Conclusions

Changing conservation paradigms may seem intimidating at first, but such major changes will in general deepen and strengthen conservation work. Ecoregional planning and ecosystem valuation are examples of two recent paradigm shifts that have transformed conservation. Working toward climate-informed conservation will force planners to accept the uncomfortable fact that nature has never been static and to create approaches to conservation that more truly reflect reality. Because time is of the essence, conservationists must learn while doing, engaging in more strategic doing and less strategic planning.

Climate-informed conservation requires a new mindset, as well as the will and capacity of conservation organizations, practitioners and managers. Although climate-informed conservation may seem daunting, failing to include the reality of climate change in creating or implementing conservation plans can produce climate-foolish rather than climate-smart results.

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