ECOLOGY

Complexities of Coral Reef Recovery

Restoring an area's natural state can have surprising outcomes. Boosting the number of predatory fish in a protected marine reserve has little effect on how well its prey controls seaweed in tropical reefs.

Ove Hoegh-Guldberg

The world's coral reefs are deteriorating—nearly half may have disappeared in the past 30 to 50 years (*1*). The plethora of threats they face include declining water quality, overexploitation, and climate change (*2*). Although there is no single panacea for these problems, marine protected areas have emerged as a potentially powerful means for managing reefs within the world's changing oceans. These protected areas create refugia for species that would otherwise be overfished. Moreover, this may have indirect benefits for the recovery of coral reefs from disturbances such as coral bleaching and outbreaks of crown-of-thorns starfish, which rapidly decrease the abundance of critical organisms such as reef-building corals. Under ideal conditions, marine protected areas should also increase fish stocks in adjacent areas as well, through the movement of species and larvae from the protected areas (*3*).

The science behind marine protected areas is still in its infancy, with few studies having established a firm scientific basis for their impact on fish populations within, and adjacent to, protected regions (*4*). Faced with few other options, however, reef managers have adopted marine protected areas as a major part of their toolkit. Last year, the world's largest marine park, the Great Barrier Reef Marine Park, adopted rezoning in which no-take areas (where fishing is totally forbidden) jumped from 4.6 to 33.4%. In a similar way, the urgency of reversing the rapid disappearance of reef resources has driven plans for no-take reserves to be placed across at least 20% of the Northwestern Hawaiian Islands Coral Reef Ecosystem Reserve in the near future. Given the huge size of such park systems, these are big investments. Yet the complete consequences of this kind of rezoning remain unclear.

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Parrotfish and seaweed dynamics on a coral reef. (**Top**) Large-bodied grazers of coral reef seaweeds such as the spotlight parrotfish (*Sparisoma viride*) find refuge within marine protected areas where they reduce the cover of seaweed, which may otherwise outcompete corals if allowed to go ungrazed. (**Bottom**) Parrotfish may consume up to four times as much benthic seaweed inside protected marine areas as they do outside such reserves, using their large beaklike mouths. Parrotfish are preyed upon by species such as the Nassau grouper on Caribbean coral reefs.

Without a firm scientific basis, it is unlikely that protected areas will be optimally designed and integrated with other fisheries management tools or will be able to deliver the high expectations of reef management (*3*). The latter is especially important if marine protected areas are to have any chance of navigating the complex social and political pathway to their adoption by countries that often have few resources to respond to threats facing their reef systems. Given the many gaps in our knowledge about how protected areas work, reef managers often have a hard time convincing reef users and fishers as to why such areas should be implemented.

Coral reefs are complex, and it can be difficult to predict how marine protected areas will influence the processes structuring these ecosystems. One of the first studies to take a critical look at the impact of protected areas on ecosystem processes appears on page 98 of this week's issue. Here, Mumby *et al.* (*5*) have focused on the effect of long-standing marine protected areas in the Bahamas Archipelago and have come up with some intriguing insights into the complex interplay among reserves, predators, and prey. The Exuma Cays Land and Sea Park (456 km^2) encompasses a large and effective protected area that was established 46 years ago and has not been fished since 1986. Mumby's team used a nested analysis that allowed them to infer the effect of reserves on predatory fish biomass and on populations of their prey. In particular, Mumby *et al.* sought to answer the question of whether implementing a marine protected area might have a long-term detrimental impact on the level of grazing, which is primarily carried out by parrotfish on benthic microalgae and seaweeds. By facilitating a recovery of top predators in this ecosystem (*5*), the level of predation on parrotfish (see the figure) could consequently increase. This may not be problematic in a fully natural ecosystem, but with the continued scarcity of the key grazing sea urchin *Diadema antillarum* in the Caribbean (*6*), a reduction in parrotfish could help seaweeds to bloom, thereby placing greater strain on reef-building corals that compete with seaweeds for space on tropical reefs.

The results of Mumby *et al.* illustrate some of the complexity of how marine protected areas might influence coral reef ecosystems. Although increases in predation reduced the size and grazing of some smaller species of parrotfish, the effect was relatively small, decreasing grazing only by 4 to 8%. This is explained by the fact that some of the larger bodied species of parrotfish are just big enough to exceed the mouth size of predators (Nassau grouper), and it is these larger parrotfish that do most of the grazing (see the figure). In fact, the protection of larger parrotfish from fishing offered by marine protected areas clearly resulted in a greater biomass of these species within such areas. This enhancement of large-bodied parrotfish within reserves was associated with a net doubling of grazing activity within reserves. This, in turn, led to a factor of 4 reduction in the abundance of seaweed on reefs within the protected areas as opposed to comparable but unprotected areas within the Bahamas Archipelago.

Mumby *et al*. conclude that marine protected areas in the Caribbean will almost always increase the level of grazing within their boundaries, despite increases in predation. The complexity they have uncovered, however, just scratches the surface of what is required to understand the functioning of protected regions. Further studies are needed to ascertain the impact of increased grazing and reduced seaweed cover on the population dynamics of corals and other key organisms. At the same time, parallel studies are needed to understand how impacts resulting from phenomena such as coral bleaching and disease drive changes within benthic communities. This will provide a balanced perspective of the impact of reserves in light of many sources of disturbance. Targeting information gaps on the impact of marine protected areas on key ecosystem processes is a priority if we are to improve the success and use of this potentially important management tool. These requirements also include the need for social and legal frameworks that allow for reserve management to adapt and change as our understanding of these management systems continues to evolve. Although these are substantial challenges, the breathtaking beauty of coral reefs and their importance to tropical coastlines and people makes their pursuit worthwhile.

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PALEONTOLOGY

A Different Kind of Croc

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A fossil crocodilian from Argentina broadens the diversity of marine reptiles. Its remarkably large head and serrated teeth suggest a very unusual kind of creature.

Crocodilians and birds are each other's closest living relative, so the evolutionary lineages leading to each group must have been on Earth an equal amount of time, at least since the Middle Triassic (227 to 242 million years ago). Birds and their extinct relatives the dinosaurs and pterosaurs constitute one of the most diverse vertebrate groups by any measure, but the journey from the common bird-crocodilian ancestor to living crocodilians has not been as uneventful as the 23 living species might suggest. Much of the extinct diversity along the crocodilian lineage was among land-living animals, such as those that developed mammal-like teeth and chewed their food (*1*) and those that held their long slender limbs beneath them like mammals (*2*), but one group—thalattosuchians—joined ichthyosaurs and plesiosaurs in the oceans and seaways of the Jurassic and Early Cretaceous. On page 70 of this issue, Gasparini *et al*. (*3*) report a fossil from the Andean foothills of Argentina that reminds us once again not to underestimate the crocodilians of the past.

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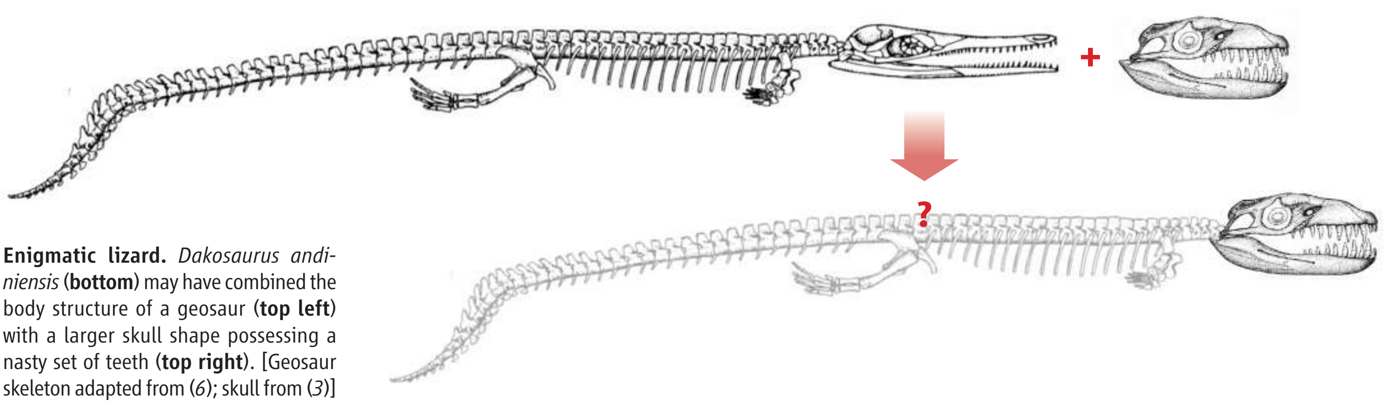
Thalattosuchians include two groups: the relatively unspecialized teleosaurids and the metriorhynchids, or geosaurs, which became highly adapted to a life-style in the oceans. Whereas teleosaurids probably looked much like a living false gharial (*Tomistoma*), geosaurs had a highly streamlined skull, large paddlelike limbs, smooth skin lacking bony plates, and a downturned tail skeleton like that of ichthyosaurs that was probably complemented by a fleshy upper lobe. Geosaur skulls were similar to those of mosasaurs, giant extinct lizard relatives, which may have replaced them ecologically in the middle of the Cretaceous.

Dakosaurus andiniensis was named in 1996 for a specimen first described in 1987, but it was represented only by a few scraps of bone and teeth. The teeth, with tiny serrations like those on the edge of a steak knife, pointed to affinities with the European *Dakosaurus maximus*, first described in 1858, which was the only known marine crocodilian with serrated teeth. When two skulls of the Andean species were discovered recently—one from the latest Jurassic and one from the earliest Cretaceous—they revealed not a low, streamlined skull like that of other metriorhynchids but a short, high one like that of land crocodilians. In addition to those of *D. maximus*, serrated teeth had been known in several extinct terrestrial crocodilian relatives, such as *Sebecus* and *Baurusuchus*, but the teeth of *D. andiniensis* are more massive than any of these.

Living crocodilians use their mouths to both capture and eat their prey, and there is a



Enigmatic lizard. *Dakosaurus andiniensis* (**bottom**) may have combined the body structure of a geosaur (**top left**) with a larger skull shape possessing a nasty set of teeth (**top right**). [Geosaur skeleton adapted from (*6*); skull from (*3*)]

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