MEETING BRIEFS

Coral Reefs Dominate Integrative Biology Meeting

BOSTON—In addition to the normal contingent of biologists from many disciplines, this year's annual meeting of the Society for Integrative and Comparative Biology, which was held here from 3 to 7 January, attracted hundreds of coral reef scientists. Some highlights follow.

Coral Partners May Enhance Reef Survival, Versatility

Many visitors to coral reefs are so taken by the beauty and diversity of the colorful fish and other reef inhabitants that they never notice one of the reef's most important components: microscopic algae called zooxanthellae that color reefs greenish gold. But the absence of these algae, which inhabit the tissue of the tiny coral animals and provide the nourishment that enables corals to form large colonies, is impossible to overlook. In the past decade, they have sometimes disappeared from large expanses of reefs throughout the world, leaving them bleached a ghostly white—and apparently dead (*Science*, 25 July 1997, p. 491). As the reefs went white, their departed brown guests caught marine biologists' attention.

No one knows what causes coral bleaching, although biologists have fingered everything from global warming to disease. But the scrutiny the zooxanthellae are now attracting is putting their symbiotic relationship with corals in a new light—and suggesting that the outlook for bleached corals may not be as grim as it had seemed.

Data presented at the meeting indicate, for example, that this symbiosis undergoes seasonal fluctuations in which about three-quarters of the zooxanthellae can be lost from a reef without harming it. Moreover, corals may still retain some of these algae in deep reserve even when they look dead white. And while it was once assumed that each species of coral associates with a particular alga, researchers now find that corals can take in different zooxanthellae depending on circumstances—a hint that when one kind of algae leaves, another might come to the rescue. "There's potential for [corals] to be fairly malleable systems," says Rob Rowan, a marine biologist at the University of Guam.

M. A. COFFROTH

T. B. SWAIN

Symbiont shuffle. Both hard *(left)* and soft *(above)* corals mix and match algal partners.

Signs that zooxanthellae come and go with the seasons emerged in studies of coral reefs off Florida and the Bahamas that marine biologist Bill Fitt of the University of Georgia, Athens, and his colleagues began 3 years ago. The researchers expected that zooxanthellae densities and the corals' reserves of proteins, carbohydrates, and lipids would be highest in the summer, when light is most plentiful. But instead, "the highest densities [are] in the winter, in the coolest part of the year," says Fitt. Their quarterly measurements indicated that by late summer the algal density often plunges to one-fourth or less of peak levels.

This suggested that the high-light, high-temperature conditions of summer somehow disrupt the algae's photosynthetic pathways. Mark Warner of the University of Georgia, working with Georgia botanist Gregory Schmidt and Fitt, has confirmed that idea, showing that a light-sensitive protein, called D1, which helps convert sunlight to chemical energy, breaks down in high water temperatures—above 30 degrees Celsius. As a result, photosynthesis declines and the algae seem to die and be expelled from the coral, perhaps because they are no longer useful. "All reef-building corals bleach every single year even when we don't see it," says Fitt. Only when algal density drops below a million algae per square centimeter, as it does in particularly hot summers with little cloud cover, does the coral begin to pale, and even then it usually recovers.

Indeed, even coral that appears dead may have a secret reserve of algae, Cynthia Hunter, a coral-reef biologist at the University of Hawaii, Honolulu, reported at the meeting. She has studied the ability of corals to withstand sudden immersion in fresh water, a threat to corals that live in estuarine areas where rainfall can cause bursts of freshwater runoff. One branching coral, *Porites compressa*, seems to die in fresh water, as it bleaches and loses all signs of soft tissue. But when Hunter examined the remaining coral skeleton, she found live tissue, including zooxanthellae, underneath. That tissue enables the coral to come back to life eventually.

Another factor may also help bleached corals bounce back: their ability to host a range of different algal guests. Evidence that they can do so first came last year when Rowan's team found that a single coral colony could have a different algal symbiont, depending on whether the coral face was in the sun or shaded. They also found that three closely related corals varied in which of the three recognized groups of algae (designated A, B, and C) they carried, depending on the depth at which the corals lived.

Other researchers are now finding the same type of algal diversity in other types of corals. Coral reef biologist Andrew Baker of the University of Miami in Florida, for example, compared DNA in zooxanthellae collected from a variety of hard corals in locations ranging from the Bahamas and eastern Panama to Australia and western Panama. He too finds that a particular coral species can associate with more than one type of zooxanthellae. Mary Alice Coffroth and Tamar Goulet at the State University of New York at Buffalo have seen similar patterns in soft corals such as sea fans. "Coral can be seen as a landscape in which different populations of zooxanthellae are competing," Baker told the meeting participants.

That diversity may help explain why one coral bleaches while another just a few yards away does not. Different zooxanthellae in those corals may respond differently to the stress that leads to bleaching, Rowan explains. Bleaching may even help the coral switch to an alga better suited to new conditions. Yet he and others caution that they still have much to learn about the ongoing conversation between the algae and the coral. "It's only beginning to come out how complex it is," says Goulet.

Farm-Fresh Corals

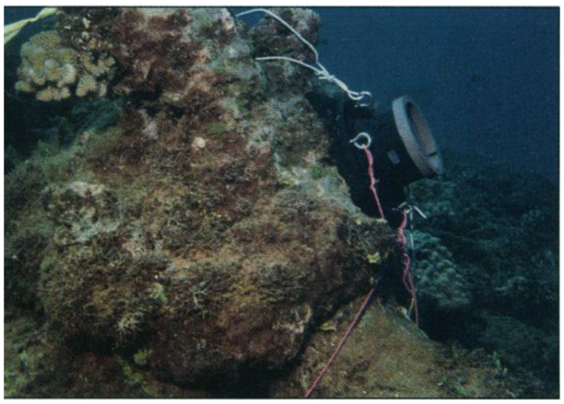
Fish and pearls now come from farms, so why not corals? At the meeting, reef scientists reported techniques that may allow aquaculturists to grow coral commercially for sale to tourists or aquarium enthusiasts, reducing the harvesting of natural reefs. The cultivated corals might also be used to reseed small swathes of reef damaged by ships, fishing, or development, says one of the researchers, Robert Richmond of the University of Guam Marine Laboratory in Mangilao.

The idea of growing corals is not new, but with these methods, "the goal is to make the [aquaculture] system simple so that it can be used by the island communities," says Richmond, whose university has been developing the system based on the discoveries he and others have made about coral reproduction.

The culture systems are catching the eye of conservationists as well as entrepreneurs. "It's dangerous to think we will grow back reefs on the kilometers scale," comments reef scientist Howard Lasker of the State University of New York, Buffalo. "But reseeding efforts [with cultivated corals] will be important in specialized cases."

Richmond's initial interest was not in reef restoration or aquaculture but in producing the many dozens of coral specimens he needed to test the toxicity of various chemicals to reefs. Before the corals could be cultured, however, his team first studied them in the wild to determine when the tiny polyp-shaped animals that form coral colonies release their gametes. This turned out to be within a week after the summer full moons.

This cycle sets the timetable for coral culturing. The researchers collect adult pieces of reefs just before the full moon and place



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Head start. Aided by this protective device, "farmed" larvae can reseed a reef.

them in tanks with running seawater. When the gametes are ready, the team siphons off the eggs and sperm released by the corals and mixes those gametes in new containers where the fertilized eggs transform into swimming larvae. After 2 days, the larvae begin to settle on glass plates at the bottom of the containers. At that point, the researchers place a larger coral colony in with the settled larvae to provide a source of the algae that the new corals need to take in if they are to survive. The corals then begin forming calci-

R. H. RICHMOND/UNIVERSITY OF GUAM

Coral crop. Letting young corals fuse yields bigger corals faster (top, right).

fied nodules—reefs in microcosm.

Thus far, the team in Guam has cultivated 10 species with this technique. Most are branching corals, although others grow into large, rounded colonies. The researchers have learned that because the closely spaced young corals in the containers quickly fuse into a single, larger colony, cultivated corals can reach souvenir and aquarium size—about 10 centimeters around—in just 5 months rather than the year it takes in nature.

Next summer, Richmond's team plans to scale up their operations to demonstrate whether mass-production of corals is possible. If all goes well, they expect to hold a workshop by fall to teach potential coral farmers these techniques, but they have already started transferring the technology to Palau, Richmond's colleague Sandra Romano reported at the meeting.

Researchers interested in reconstituting damaged coral reefs are studying the cultured corals to see if they can be used in transplants instead of natural corals. "Transplanting coral is viable, but you always get some mortality," Richmond explains.

In one experiment, Laurie Raymundo, a coral reef biologist at Silliman University in the Philippines, and her colleagues showed that cultured coral colonies can survive when transplanted to natural reefs, provided the transplants are big enough. When they grafted colonies they had cultured using an approach similar to Richmond's onto a healthy reef off Negros Island in the central Philippines, the researchers found that only about 10% of corals with diameters smaller than 6 millimeters survived. But nearly 70% of those with diameters of 10 millimeters or more lived. The team is now monitoring the transplanted corals to see whether they will continue to thrive and to grow.

Throat Pumps for Better Breathing, Longer Run

For years, researchers have argued about whether lizards can run and breathe at the same time. Their anatomy suggests that they can't, at least not well. But when the wide-ranging kind of lizards called monitors run on a treadmill, their blood remains rich in oxygen—suggesting that these animals breathe just fine as they run. "It's been a fairly contentious argument for over a decade," says David Carrier, a functional morphologist at the University of Utah, Salt Lake City. Now it may be over.

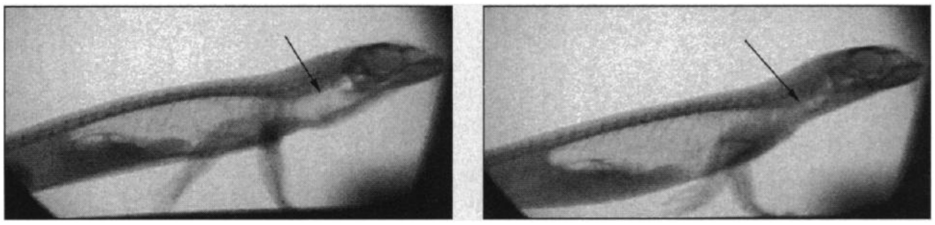
New data presented at the meeting by physiologist Elizabeth Brainerd of the University of Massachusetts, Amherst, and her colleagues suggest that monitors are a special case. They have found that the large throat pouches found in these lizards serve as accessory air pumps, forcing air into their lungs and overcoming the anatomical limitations of other lizards. The finding "seems to have resolved the conflict," comments Jaap Hillenius, a physiologist at the College of Charleston in South Carolina. "Some lizards can breathe and some lizards cannot."

Mammals use a specialized muscle—the diaphragm—for breathing, freeing the other muscles for locomotion. But in lizards, the same rib muscles that cause the lungs to expand and contract also make the lizard's body stay upright and wiggle from side to side as it runs. As a result, these animals generally can't breathe hard when they need to most and "would have had a problem with sustained locomotion," says Carrier.

Brainerd got her first clue that monitors might be an exception when she made an x-ray video of a monitor lizard in motion. It revealed that the expandable gular region of the throat was filled with air and seemed to be expanding and contracting.

Others had previously noted that when monitors breathe, they exhale all at once, but they seem to inhale in a series of small breaths. Brainerd found that those breaths feed air to the gular pouch, which acts as a pump. With each inhalation, she found, the gular region would pump several times, pushing air down into the lungs. Another sign that the pouch aids breathing is that its movements correlate with the lizard's degree of activity. "The faster they run, the more they pump; the longer they run, the more they pump," Brainerd says.

And when she, Tomasz Owerkowicz of Harvard University, and Colleen Farmer and James Hicks of the University of California, Irvine, prevented the pouch from pumping by propping the lizards' mouths open, the animals couldn't take in oxygen as well as before. When they ran on the treadmill at 1 kilometer per hour, their oxygen intake dropped 22%; at 2 kilometers per hour the decrease was 37%. "The faster they go, the more constrained they get," she adds, just as predicted for lizards



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Breathe deeply. X-rays reveal the monitor's expanding and contracting throat pouch (arrow).

who can't breathe and run.

These results help explain why monitor lizards can chase down their prey while many of their reptilian cousins sit and wait to snag a meal that comes along. They also show how evolution can solve a single problem in different ways. They suggest that the lizardlike early tetrapods, thought to be the evolutionary ancestors of both mammals and modern lizards, could run only in short, quick bursts before they used up the available oxygen and needed to stop and take a breath, so to speak. "Unless there was a change in the basic body design, you couldn't have animals with high stamina," says Carrier. Mammals solved the problem by evolving a diaphragm muscle, and monitor lizards came to have gular pumps.

–**Elizabeth Pennisi**

MARINE ECOLOGY

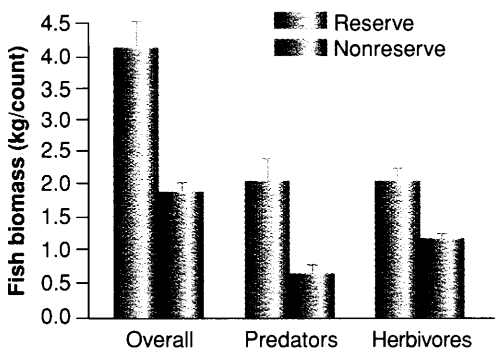
Overfishing Disrupts Entire Ecosystems

In the face of declining fish stocks, the managers of many of the world's fisheries have been forced to take often drastic measures to prevent total collapse. These include, for example, a complete ban on fishing the Grand Banks off Newfoundland and quotas that limit takes, such as those now imposed on fishing vessels in European Union waters. But a new analysis of global fish catches over the past 45 years, which appears on page 860, suggests that even more drastic action is urgently needed.

The study—conducted by Daniel Pauly and Johanne Dalsgaard of the University of British Columbia in Vancouver and colleagues at the International Center for Living Aquatic Resources Management in Makati, the Philippines—concludes that humans are inexorably fishing down marine food webs as larger and more commercially valuable species disappear, creating impoverished, less valuable ecosystems. Complete fishing bans currently apply to less than 1% of the world's fishing grounds, but fisheries experts say the findings of this new study indicate that more such protected areas must be created if there is to be any chance of salvaging vanishing ecosystems. "Most researchers work at the fishery or species level, but this study looks at the global picture and reveals just how unsustainable our exploitation of marine resources is. It's a wake-up call," says marine researcher Elliott Norse, president of the Marine Conservation Biology Institute in Redmond, Washington. (See Research Commentary on p. 821.)

To come to this conclusion, Pauly, Dalsgaard, and their colleagues first used an analysis of the diet of 220 key species to assign to each species of catch a trophic level, a rating describing its location in the food chain. Trophic level 1 comprises the primary photosynthetic plankton, while a top predator, such as the snappers inhabiting the continental shelf off Mexico's Yucatán Peninsula, gets a rating of 4.6.

Then, the team analyzed data collected by the United Nations Food and Agriculture Organization on catches in the world's major fisheries from 1950 to 1994 to determine whether the trophic levels had changed with time. This showed that there had been a gradual shift from long-lived, high-trophic–level fish (such as cod and haddock) to low-trophic–level invertebrates and plankton-feeding fish (such as anchovy). Overall, the researchers found a steady mean decline of about 0.1 trophic levels per decade in the worldwide catches. What's more, Pauly says, "this is probably an underestimate, as catch measurements from the tropics are poorly recorded."



SOURCE: D. PAULY ET AL.

Bouncing back. Fish stocks recovered 2 years after a small reserve was set up off St. Lucia.

The results also indicate that the quantities, as well as the quality, of the catches are decreasing. At first, skimming off the top of the food chain and then moving down to lower trophic levels can lead to increased catch sizes, because top predators require a large reservoir of prey to sustain them. But the new research shows that, in most instances, when the top predators are removed, catches stagnated or declined, apparently because the populations of the predators' competitors for food expand. "The Black Sea provides a good example," Pauly says. "There's been a huge increase in jellyfish as their economically valuable competitors have been removed."

As a result of this overfishing, the number of main fisheries in the Black Sea has fallen from 26 in the 1970s to five now, says Norse. "Present fishing policy is unsustainable. The food-web structure is changing," says Pauly. "At least 60% of the world's 200 most commercially valuable species are overfished or fished to the limit," says Claude Martin, director-general of the World Wide Fund for Nature.

Pauly argues that there is an urgent need to create protected areas, where fishing is not allowed. Although other measures, such as quotas, limiting fishing time at sea, changing fishing gear, and controlling pollution are crucial, they are difficult to implement quickly and control, he says. And there is growing evidence that protected areas can be highly effective in restoring and maintaining marine ecosystems. Such areas on the Georges Bank off Massachusetts were created only in 1994, but researchers are already finding an increase in the size and spawning populations of key fish species, as well as a rapid increase in the bottom-dwelling scallop population, says a spokesperson for the National Marine Fisheries Service in Woods Hole, Massachusetts.

Even tiny protected areas can be very effective in some regions. Callum Roberts of the University of York in the United Kingdom says reserves of just a few hectares on tropical coral reefs have boosted fish stocks and helped maintain long-lived large predators.

The fishing industry is also now beginning to back this policy. In the United Kingdom, the industry now backs plans for no-fishing areas as a key way to develop the European Union's fishing policy in the face of declining stocks, says Roberts. "At the very least, they can offer quick and simple protection while the complexity of long-term sustainable fishing policies are developed," says Norse.

But Pauly's results have set a clock ticking on the development of such policies. "In 30 to 40 years, our fisheries could have moved down another 0.5 of a trophic level in overall catch, which is an enormous change," he says. "If things go unchecked, we might end up with a marine junkyard dominated by plankton."

–**Nigel Williams**