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Journal Title: ~~American~~ New scientist.

Volume: 155 **Issue:** 2099
Month/Year: september 13 1997 **Pages:** 28-32

Article Author:

Article Title: S. Pain; Swimming for dear life

Imprint: [New Haven, Conn., etc., Sigma Xi, etc.]

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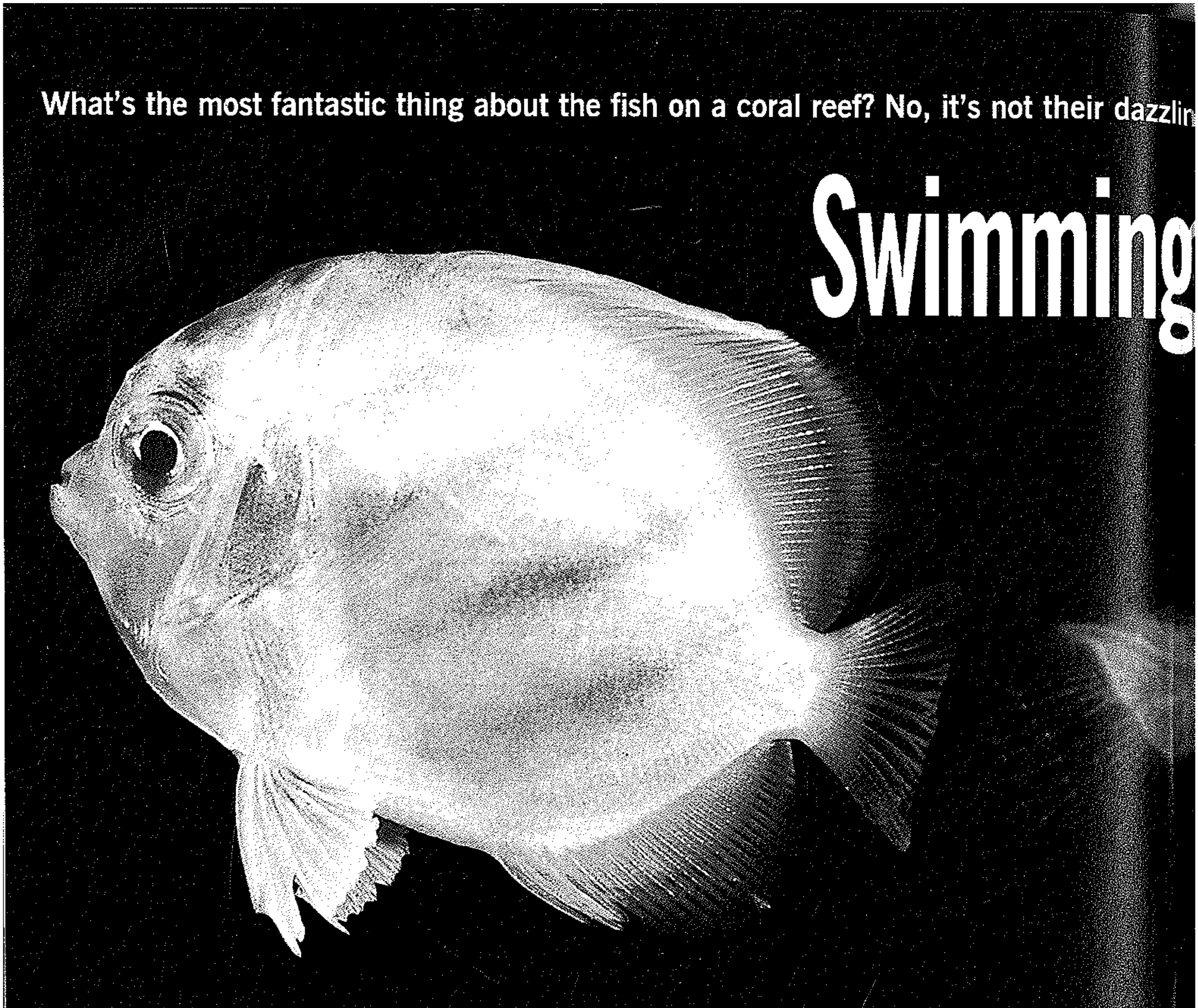
What's the most fantastic thing about the fish on a coral reef? No, it's not their dazzlin

Swimming



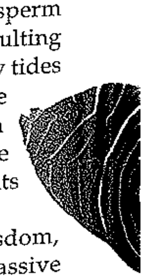
Rudie H. Kuiter/Norbert Wu

JEFF LEIS's job requires total concentration. He swims through the crystal waters of the Great Barrier Reef, his eyes glued to a single, tiny fish larva swimming in front of him. Leis, a fish expert from the Australian Museum in Sydney, has spent hundreds of hours in the waters around Lizard Island following his tiny prey. It is not an easy job. Each attempt requires two divers—one to keep the scarcely visible animal in view, the other to operate a stop watch, compass and depth gauge. A third person sits above in a boat following their bubbles and watching for sharks. Sometimes there is another problem: the fish takes off with such speed that the divers can't keep up.

A little farther up the coast, Eric Wolanski is also watching fish larvae. The difference is that his tiny specks of life are artificial, the creation of a computer program—and there are many thousands of them. Wolanski is an oceanographer who models currents and fish movements around the Great Barrier Reef. Crunching data collected over almost two decades, Wolanski's program has also revealed some astonishing things about the skills of fry that live around coral reefs.

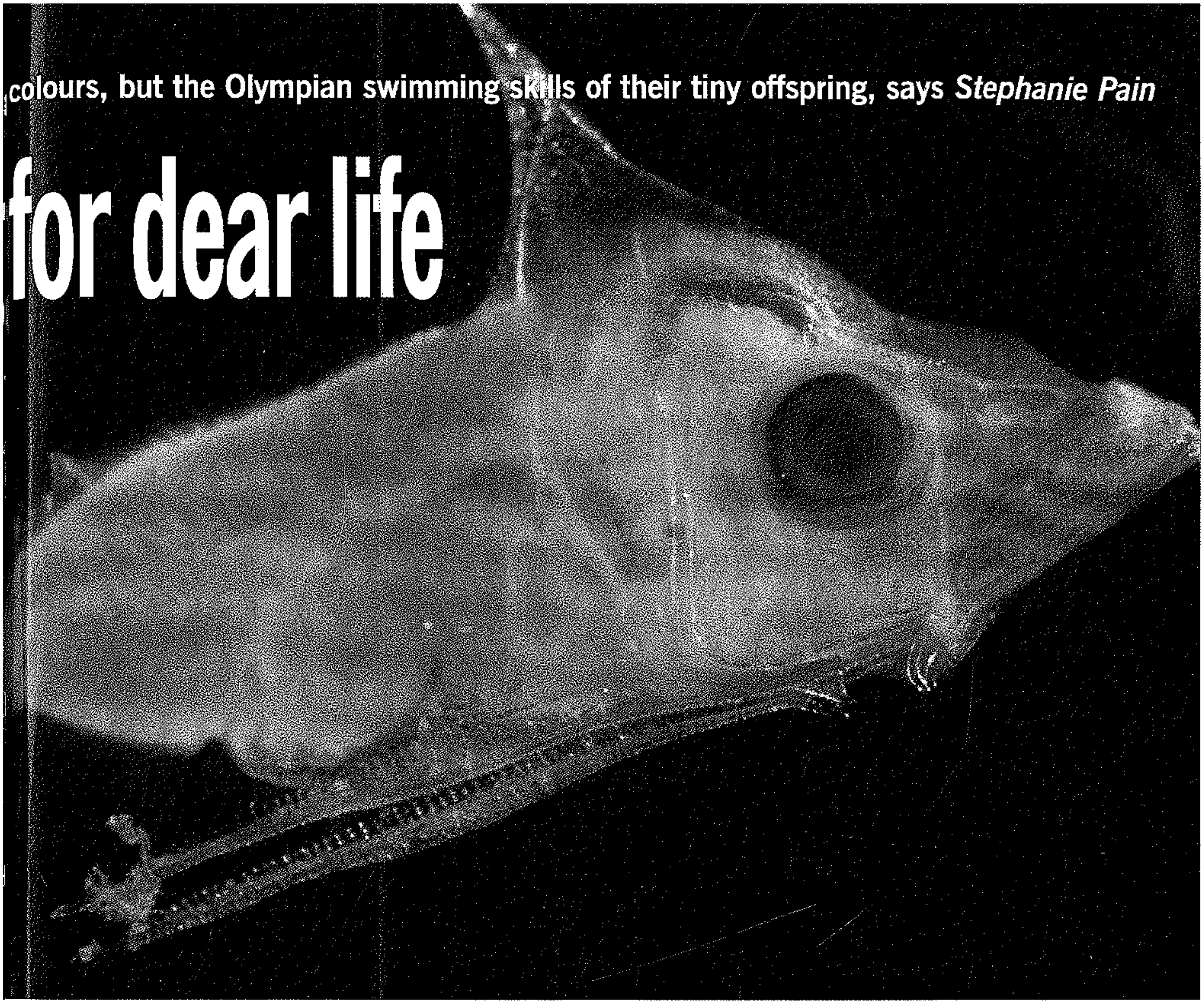
Both low-tech and high-tech approaches have led to the same conclusion. Coral fish fry are not the helpless creatures everyone thought. Although they are often only millimetres long, these larvae have the speed and endurance to free themselves from the grip of an ocean current and the ability to detect a reef from at least a kilometre away. This new discovery will change the way biologists think about the colonisation of reefs, and the best way to protect them from overexploitation.

Like most marine animals, reef fish have two distinct stages in their life. The adults tend to stick close to home, often remaining on the same part of a reef all their lives. For these fish, the deep water between coral shoals and islands is an uncrossable void. By comparison, their offspring lead adventurous lives. Almost all reef fish shed their eggs and sperm directly into the water, and the resulting embryos are quickly swept away by tides and currents. Developing larvae spend the next few weeks in open water until they are ready to settle down and adopt the sedentary habits of their parents.



According to conventional wisdom, these offspring of reef fish are passive colours, but the Olympian swimming skills of their tiny offspring, says *Stephanie Pain*

for dear life



specks in the plankton, hapless scraps at the mercy of currents, tides and wind-driven movements of the ocean's surface waters. As a result, only a tiny proportion of the young produced by reef fish will ever find a home, fetching up on a distant reef more by chance than design. Many more must be "lost at sea", having failed to find a place to settle.

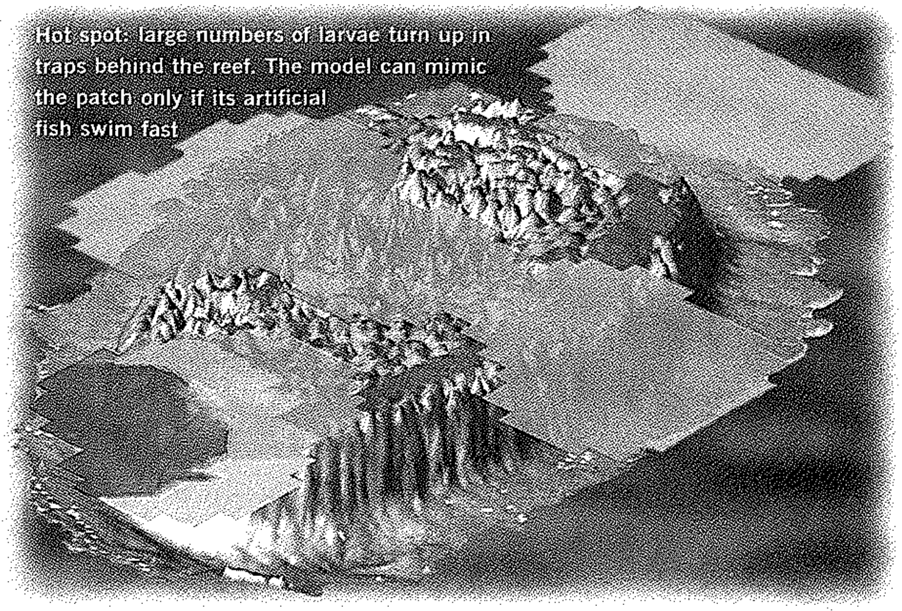
"For most world fisheries, we are told there is a tremendous amount of wasted fish larvae," says Wolanski, who works at the Australian Institute of Marine Science near Townsville in northern Queensland. Even so, there were thought to be far more larvae around than reefs could support—plenty of spare fish to replace stocks reduced by overfishing.

But the story that is now unfolding is almost exactly the opposite. Larval fish are not passive, nor are there enough waiting in the wings to fill the gaps left by fishermen with hooks, crowbars, dynamite and cyanide.

Most studies of fish larvae have been carried out on species from temperate waters, such as cod and herring. These are much less well developed than coral reef species at a given size and swim very badly—in the lab at least. Unlike herring and cod, the young of reef fish have good reason to travel under their own steam. When the time comes to settle, the larvae have to find a small reef in a big ocean, otherwise they won't be able to complete their life cycle.

Leis and his fellow fish-followers have timed more than 50 species belonging to 15 families in the waters of the Great Barrier Reef and off Rangiroa Atoll in French Polynesia. Their latest findings leave no doubt that these small fry are champion swimmers.

On average, the young fish could do a pace-setting 20·6 centimetres a second, equivalent to almost 14 times their own body length each second. An Olympic swimmer who could match this would finish the 100 metres in 3 seconds. Not surprisingly, the bigger larvae, such as those of surgeonfish and soldierfish, swim faster, but taking size into account, some of the smaller ones give more impressive performances. A small damselfish, for instance, achieved an astonishing 50 body lengths a second. The all-time champion, a soldierfish followed off Rangiroa, averaged 56 centimetres a second over 10 minutes, but put on such a spurt in the final two minutes that it left the divers behind.



Hot spot: large numbers of larvae turn up in traps behind the reef. The model can mimic the patch only if its artificial fish swim fast

T. Mizushima/Photonica Tony Stone/P. Parks/MoYung Productions

'We were phenomenally surprised by how good they were. We had no idea they could do this much'

At James Cook University in Townsville, PhD student Ilona Stobutzki has tested both the speed and the staying power of larval reef fish. She released them into specially designed race tracks, where she could control the speed at which the water flowed through the tracks. The fish had to swim against the current to avoid being swept into a mesh fence across the track.

Stobutzki put the larvae of dozens of species through their paces, increasing the speed of the "current" every five minutes until the fish could no longer keep up. Even the small-bodied species reached 40 centimetres a second. To test their endurance, Stobutzki made the fish swim against a current of 13·5 centimetres a second—the average around Lizard Island—and kept them swimming until they tired. This time, the champion was a surgeonfish, which kept going for 94 kilometres without a rest.

Taking control

"We were phenomenally surprised by how good they were," says Stobutzki. "We had no idea they could do this much. This means that in the final stages before they settle, they have a huge degree of control over where they go."

Both Stobutzki and Leis have also found clear indications that before they settle down, the young fish have a sense of direction and can detect reefs from at least a kilometre away. Leis captured larvae close to Lizard Island just as they were about to settle at night—luring them into traps "baited" with a bright fluorescent light. The next day, he took them back out to sea, a kilometre from the reef, and freed them one at a time. "The fish chooses where it's going and the divers follow it," says Leis. What he found surprised him. About 80 per cent of the larvae swam in a very definite direction—not towards the reef but away from it, regardless of whether the reef was to the east or the west of them.

This shows that larvae can detect a reef from this distance, says Leis. He believes the larvae chose to swim away because the experiment was done during daylight. Most studies suggest that larvae arrive on a reef after sunset, when the big schools of plankton-eating fish that form the "wall of mouths" around a reef have retired to their night-time lairs. Once on the reef, the young fish must find a safe place very quickly—in the deadly tentacles of an anemone in the case of the clownfish, and among the branching corals for the black-and-white humbugs. By morning, any small fish that has not found suitable shelter is likely to be eaten by the hordes of emerging predators.

Stobutzki tried another approach—and her results suggested that Leis might be right. She collected fish in light traps and then placed them in an elaborate apparatus close to Lizard Island. When the fish were released from a central chamber, they could choose to swim either towards the reef or away, only to be captured in another chamber of the trap. The experiments were done at night and every time the fish headed reefwards.

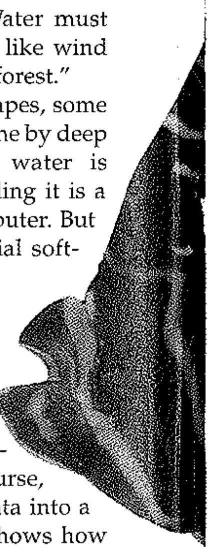
At the Australian Institute of Marine Science, Wolanski and fish biologist Peter Doherty have just reached the same conclusions. But instead of looking at individual fish in a small patch of water, they analysed the movements of hundreds of thousands of larval fish in a huge section of the Great Barrier Reef, trying to reconcile the distribution of fish with the physical movement of the water.

Currents and tides

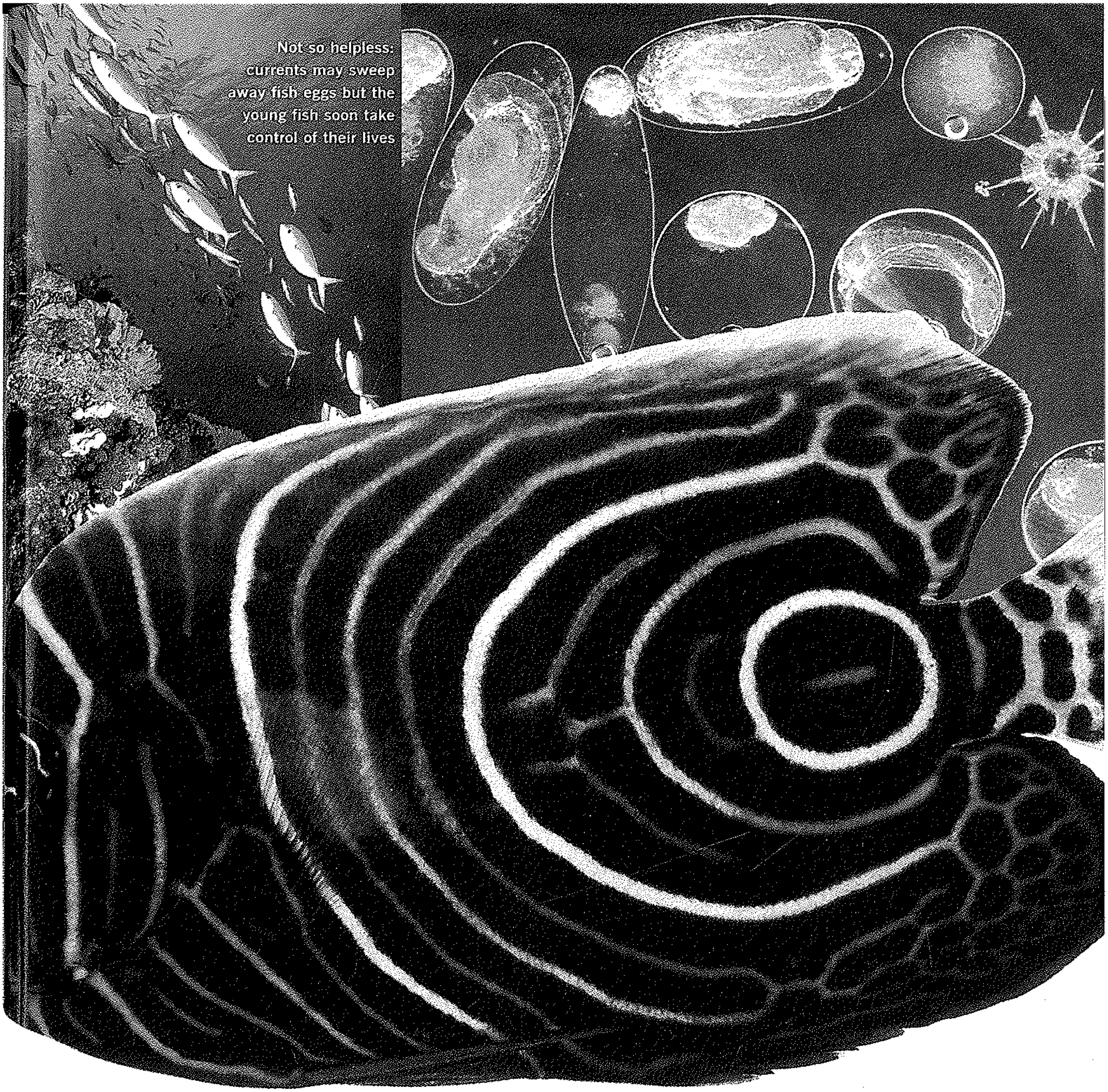
Until now, models of the movements of fish have been based on patterns of movements of the water. "All you needed were modellers to tell you where the water was going and that would tell you about the fish," says Leis. "That's no longer enough."

Wolanski has spent the past 18 years collecting data on the patterns of water movement around some of the three thousand islands and shoals in the Great Barrier Reef. The central part is "chock-a-block" with reefs, says Wolanski: "Water must find its way through the reefs like wind blowing through the trees in a forest."

With reefs of all sizes and shapes, some separated by shallow water, some by deep channels, the circulation of water is extremely complex and modelling it is a Herculean task even for a computer. But with supercomputer and special software donated by IBM, Wolanski has plotted the way water circulates through this obstacle course, turning a confusing mass of data into a 3D computer animation that shows how the water moves around each reef, sometimes swirling and creating eddies behind the obstruction before breaking free and travelling on down the chain of reefs.



While Wolanski has been collecting data from current meters and remote sensing satellites, Doherty has spent the past seven summers trapping larval fish to build up an equally detailed picture of what they are doing in those waters. He has discovered that in this part of the Great Barrier Reef the young of all sorts of reef-dwelling fish—from damselfish and angelfish to commercial species such as groupers and sweetlips—approached a reef from upstream. They came in pulses, arriving on the reefs at the time of the new



Not so helpless: currents may sweep away fish eggs but the young fish soon take control of their lives

Moon—the darkest nights of the month. Soon the larvae began to concentrate in hot spots around the edge of the reefs, especially off the downstream end.

On the face of it, this might be explained by hydrodynamics. Eddies that form in the lee of a reef might trap larvae, holding them close to the reef and providing them with an opportunity to settle. But in the Great Barrier Reef, these eddies are unstable and don't last long enough to retain the fish. Other findings also made Doherty and Wolanski suspect that physics was not the only force in operation. For instance, if all larvae were passive particles, why were there no young of open water fish in the traps set near the reefs? And why were there such large concentrations of reef larvae? It looked as if the bluewater fish were deliberately keeping away, while the larval reef fish were deliberately making for the reefs.

With so much data, the only way to find out what was really going on was to turn to the computer model and simulate the behaviour of fry by creating artificial fish. After feeding all his oceanographic data into the model, Wolanski introduced a cloud of larvae moving towards the reefs. In the first computer run, the larvae were treated as passive particles. They did turn up in the lee of the reefs, as Doherty's traps had shown. "The model with passive larvae did predict that they would be there," says Doherty. "But only at the same densities as elsewhere around the reef."

At the next attempt, Wolanski gave the fish the ability to swim and a sense of direction. This time, the model produced the same sort of results as the biologists. "The concentrations are a hundred times those in the original patch and that's what is observed from trapping," says Wolanski.

Making some fish swim faster than others—mimicking the differing abilities of large and small larvae—produced an even closer match to Doherty's observations: larger larvae were spread more evenly whereas smaller ones invariably collected in the lee of a reef, where currents are weaker.

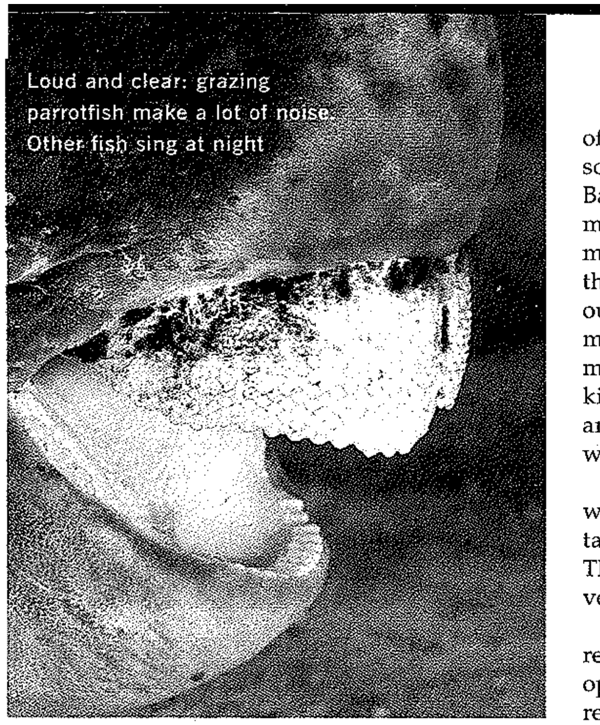
Clearly, larval fish are strong swimmers, and there is good evidence that they can sense where a reef is from some way off. The question is how do they know? What can they sense and from how far away?

"We can eliminate some possible cues," says Leis. Observations suggest that they don't rely on currents or wind-driven waves. The fact that Leis's larvae swam away from the reef regardless of their position relative to it rules out a sense of direction based on the Sun or the Earth's magnetic field. Vision can also be ruled out. "Initial orientation starts at distances well beyond the extent of vision," says Doherty.

Noisy and smelly

That leaves two possibilities: the fish could be homing in on sound or some sort of smell. Fish can detect chemicals in the water. Clownfish, for example, rely on scent to find their protective hosts in the dark. Some species, such as the humbug damselfish, detect others of their kind by their smell. "But we're talking about a scale of a few metres, not the sorts of distances you need to find a reef," says Leis. Besides, in the mixed-up waters of the Great Barrier Reef, any reef smells will be so widespread that they will be of no help in pinpointing a particular reef. So that leaves sound.

Almost nothing is known about the auditory powers of larval fish, but reefs are very noisy places. The crashing of surf on coral can be phenomenal. Inside the outer barrier reef, however, the wind whips up surface waves that generate enough noise to drown out the coral breakers. "But lots of reef animals make noises," says Leis. "Sea urchins make scraping noises as they graze over the coral and so do parrot fish." Fish can also generate their own music by grinding their jaws or "drumming" on their swimbladders with certain muscles.

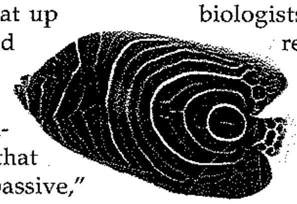


Loud and clear: grazing parrotfish make a lot of noise. Other fish sing at night

Norbert Wu

The best bet is probably the "nocturnal chorus"—a piscine equivalent of the dawn chorus. Navy scientists have detected it in waters throughout the tropics. "They think it originates from fish, although they've tried to catch them and failed," says Leis. "It has peaks of intensity in summer, at night and at the time of the new Moon. All three of these are peak times for recruitment of larvae to reefs."

The crucial question now is at what stage in their development do larval fish begin to take control of their fate? This depends largely on how quickly their swimming abilities develop. Leis has found that small damselfish can swim at up to half their eventual top speed by the midpoint in their larval development.



"If we can look at the earliest stages, we might find that even they are not entirely passive," says Stobutzki. "They might be able to move vertically in the water—perhaps into water that is not moving so fast."

The astonishing skills of young fish have far-reaching implications, both for biologists and for those responsible for protecting reefs. The findings destroy the notion that larvae are inevitably swept away from the place they are born to settle somewhere far downstream. Some young fish may resist the movement of water and remain close enough to their home reef to make their way back when the time comes to settle. In the case of isolated oceanic reefs, this may be crucial because the alternative is the loss of most of each year's young. It may not be so important for fish on the Great Barrier Reef, where there are plenty more reefs nearby. There, the larvae may use their skills to ensure that they don't travel too far, or end up outside the barrier altogether. They may travel only a few tens of kilometres rather than the hundreds of kilometres people had assumed—and there may be definite "highways" linking particular reefs.

"What influence larvae have on where they end up will be important for those who manage reefs. They will have to think about things very differently," says Leis.

With most of the world's coral reefs seriously threatened by development and overexploitation, many reef ecologists believe that the only way to preserve their fish populations is to create a network of refuges, reefs or parts of reefs that are out of bounds to fishermen.

The concept is simple. If you allow some fish to reach adulthood, they will produce huge numbers of offspring which will be carried on the currents to restock any overexploited reef—perhaps hundreds of kilometres away. But the discoveries in Australia suggest that the strategy is badly flawed. First, it looks as if a much larger proportion of each year's young make it to a reef and so have a good chance of settling. That destroys the myth that there is a huge surplus of spawn to fill in the gaps on overfished reefs.

Added to this, if refuges are to work, biologists need to know if a reef replenishes itself, or where there is traffic between reefs, they need to know how particular reefs are linked. "At the one end of the spectrum, you would have to manage each reef independently. At the other you would have to protect great chunks of reef systems," says Doherty.

Leis has another suggestion. "If we can find out exactly what it is the fish homes in on, we might be able to use that to guide larvae towards overfished or damaged reefs." But discovering the musical preferences of tiny fishes is likely to be as difficult as chasing them in the dark. □

Further reading: "Larvae dispersion in coral reefs and mangroves", Eric Wolanski and Joe Sarsenski, *American Scientist*, vol 85, p 236 (1997)