Vision and Birds of the Night

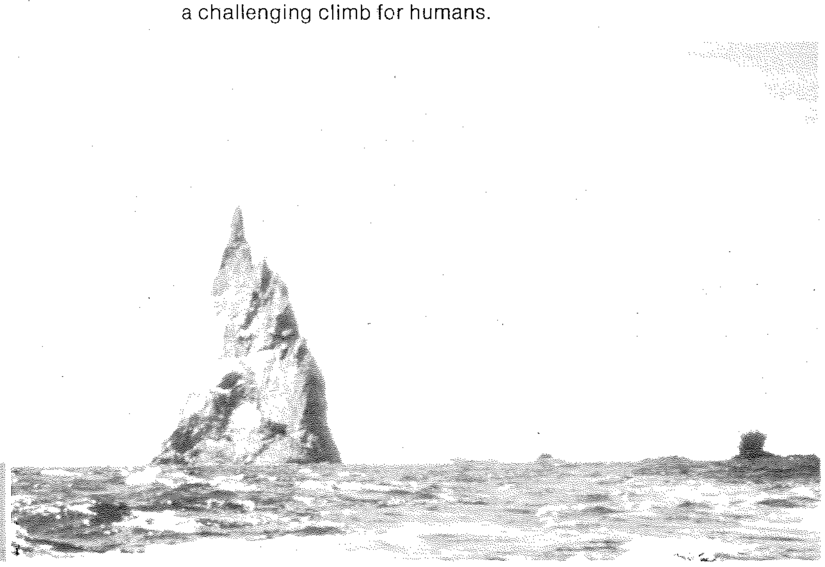
by JOHN D. PETTIGREW, MD

My interest in birds dates back to my medical school days, when I was a member of the first party to climb Ball's Pyramid, a 2,000-foot spire of rock that sticks straight up out of the ocean in the South Pacific not far from the Australian coast. There had been numerous previous attempts to climb this rock, but most of them failed because of various problems like seasickness and huge waves that made it almost impossible to land on it. In 1965 our party was able to land by swimming in through the big swells.

There were tremendous problems getting around to the climbing site even after we got ashore. And the standard of rock climbing was also fairly high—most particularly at a point near the top called the Cheval Ridge, which is so narrow that the safest way to climb it is to sit astride it, like a horse. In fact, it's possible to spit into the ocean from either side of this ridge.

Apart from all the difficulty and adventure, one of the attractions of the place for me was that it was a gigantic rookery. There are thousands of birds here.

Ball's Pyramid is a 2,000-foot-tall spire of rock rising out of the South Pacific near Australia—a home for thousands of birds but a challenging climb for humans.



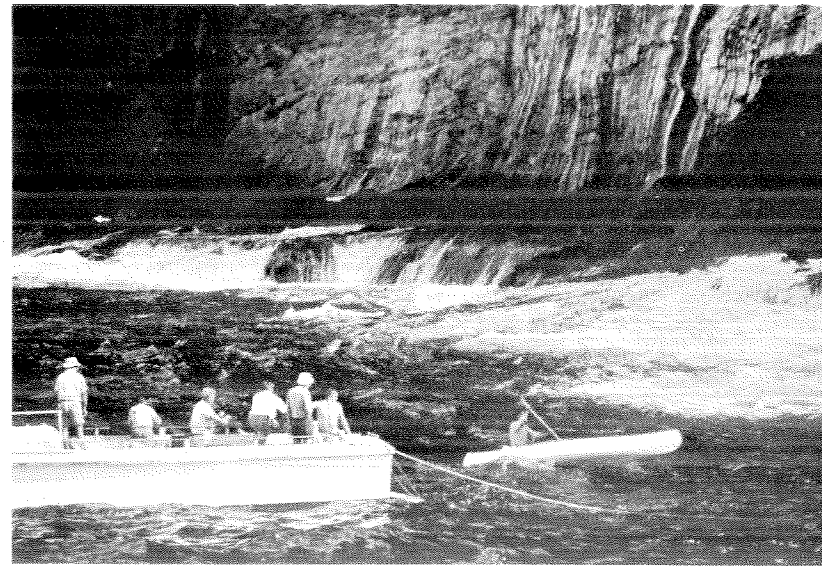
At that time I didn't have any really good reason to justify studying them scientifically. Last year, though, a rationale was provided for fitting this adventure into my science—a discovery I made with Mark Konishi, professor of biology at Caltech and a neuroethologist with a lifetime's experience studying birds.

We were working on the brain of the owl, and there's a part of it called the *Wulst,* which under a microscope looks totally different from the human visual cortex. I'll remind you that owls evolved independently from us about 200 million years ago, so they're a separate evolutionary line. When we studied this part of the brain, we discovered to our surprise that it functioned in the same way as the visual cortex of monkeys, and presumably the visual cortex of man. We also discovered that, just as in kittens and baby monkeys, and presumably baby humans, this part of the brain is really sensitive to what the baby owl sees or does not see in his early development.

NATURE AND NURTURE IN THE OILBIRD: A NATURAL DARK-REARING EXPERIMENT

This fact led us to look more widely at the bird kingdom, and we were intrigued by reports of a strange bird from South America, called the oilbird, which has many puzzling features. First, it spends its first 100 days of development in total darkness. We found this puzzling because of our studies showing how important visual experience is in early development. The oilbird, *Steatornis caripensis,* also had a fantastically well-developed visual system, and yet it was reported to be able to fly about in caves in total darkness.

It's called the oilbird because when it was first described by Alexander von Humboldt back in 1799, the practice then was for Indians to pull the baby birds



The rocky shore of Ball's Pyramid is no more hospitable close up than from a distance, but on his second trip in 1969 Pettigrew and his friends managed to get a canoe through the heavy swell.

A Caltech biologist speculates that there is a relation between the kind of eyes found in a couple of exotic birds and the fact that they live nocturnal lives

out of their nests and roosting places high in the caves and boil them down for oil. The babies actually weigh more than the adults because they're fed with palm nuts, which are very oily. In South America the natives call it *guácharo,* which refers to the raucous cry of the bird. It's about the size of a crow, and it uses echolocation like a bat. It emits a sharp clicking cry and listens to the echo being returned from obstacles in its path. Unlike the bat's cry, this one is audible to the human ear.

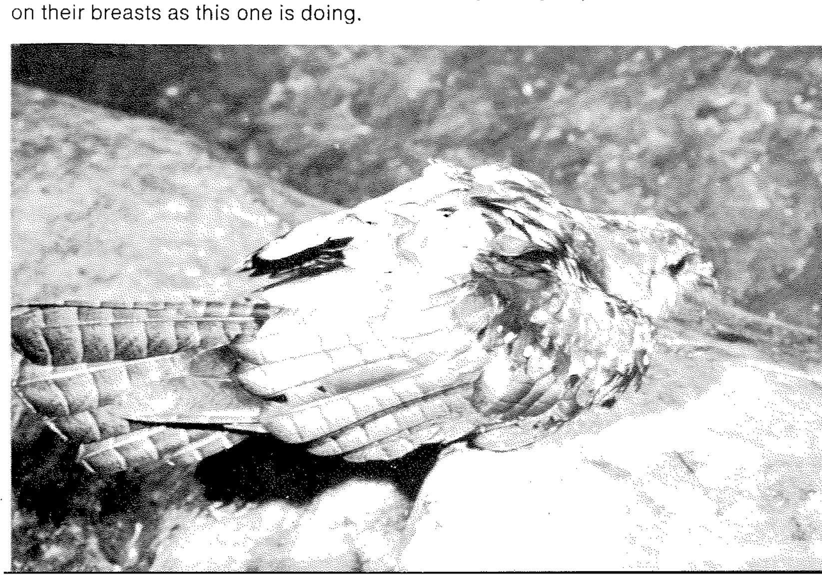
There were so many puzzles about this bird that we decided the only way to solve them was to go down there ourselves and sort them out. And for three weeks at Christmas of 1976 we went there, funded by the National Geographic Society. Oilbirds are found all the way from Trinidad to Venezuela, in northern Colombia, perhaps in Panama, Ecuador, and northern Peru. We studied the bird in the Tolima Province in Colombia, about 200 kilometers from Bogota.

My first introduction to the village where we hired some guides to take us to the cave was to arrive there with two flat tires—the car being jacked up beside the road about six miles back. At the local service station, Miguel Soler was very rapidly able to fix the tires with his vulcanizer kit, and he then joined our party. He's a very strong man who knows a lot about the cave. Our other guides included Marcos Meneces, a farmer with a wonderful knowledge of the local wildlife. In the dead of night he can tell you what just about every sound is. You'll hear a weird gurgle, and he'll say *chorola,* which is the local word for a tinamou. You'll hear another call, and he'll say *buhio,* which is the local name for a nightjar, and so on. He also has a fantastic knowledge of all the plants and all the animals in the area. In addition, we were helped a great deal in getting up to the cave by *Mediamundo* (which means "half a world"), a one-eyed horse. In return for the help he gave us in getting up the hill, we had to help him a little on the switchbacks. He could make the left-hand turns very well because his left eye could see, but on the right-hand turns you had to tug a little on the reins so he wouldn't go galloping off into the jungle.

Mark and I were very appreciative of *Mediamundo's* help because both of us suffered from a nasty lung complaint. We inhaled some insects in the cave, and both of us came down with acute breathlessness and chest pain. So we had a little trouble getting up the hill.

One member of our party, Nobua Suga, an expert on echolocation from Washington University in St. Louis, got very excited as we approached the cave. He had spent his life studying echolocation in bats, whose echolocating cries are largely inaudible to the human ear. It was therefore quite a thrill for him to experience directly the readily audible clicks of the oilbird. To get access to the cave and actually watch the

Oilbirds are beautifully marked brown and gray birds about the size of a crow. Their feet are so weak that they always "perch" on their breasts as this one is doing.



Looking fierce as a predator, the oilbird actually lives solely on fruit. The cat-like whiskers probably help guide the parent birds in feeding their young in the cave's darkness.

birds we had to swim down into total darkness—and you wouldn't want to swim too far because the stream ends in a big waterfall. The cave is full of birds, all circling around, and it was one of the most exciting experiences of my life to hear these birds effortlessly hovering overhead and clicking away.

But let me tell you a little about how these birds live. What do they feed on? The answer to that was fairly easy to determine because the seeds of the fruit they eat are littered underneath the nests in the cave, and many of these seeds germinate in total darkness. In 1799 when von Humboldt visited the cave in Venezuela, he was unable to persuade the natives to venture very far into the cave. They were frightened by the sounds of the oilbirds and the darkness, and by the ghostly white plants stretching up. For us, the plants offered a very convenient way of identifying just what the oilbirds eat, because I was able to talk the less superstitious natives of 1976 into collecting samples of the seeds. I took them outside, where we washed them in the creek, and then I could identify what the seeds were and match them with seeds from many of the local plants. It turned out that out of the 1,300-odd seeds I counted, 1,257 were of the variety that the locals call

Inside the total darkness of the cave the oilbird has a rather slow, hovering, vertical flight pattern, and each bird constantly emits clicking noises to help orient itself.

chonta—a type of palm nut. They are distinctly unpalatable, and I don't know how the oilbirds stand them. Some of the fruit they eat is more palatable. For instance, a *mamonsillo,* a delicious fruit that is sold by the local children on the streets, is also eaten by the oilbirds, and we fed this fruit to the birds we kept for a few days.

What about the chicks? I went down to Colombia to find out something about baby chicks, and unfortunately, because of bureaucratic problems and delays, I wasn't able to make as many studies as I would have liked. They live in nests made of mashed-up palm-nut debris, which is added to every year until some of the nests get four to five feet tall.

These baby birds spend their first 100 days in the nest, which is a very long period of development for any bird. How do they manage without getting any visual experience? I don't have all the answers, but I have a few suggestions, one of which comes from studying the pattern of flight of these birds.

TWO MODES OF FLIGHT

When they're in the cave in total darkness, the oilbirds constantly emit clicks and listen for echoes so they can judge the distance and location of obstacles. In this situation they have a vertical, hovering flight. This mode of flight is rather slow, but even so it's impossible to catch them in a net—presumably because they feel the net with their wings and also with their whiskers. (They have very large whiskers, bigger than a cat's.) They are flying so slowly and they are so maneuverable that it's possible for them to feel the net and retreat.

In contrast, if there is the least bit of light, they stop clicking immediately, and they fly in a regular bird fashion, with the body horizontal. At the mouth of the cave, when there's a little bit of starlight, the clicking stops and the bird flies in a fast, soaring fashion, very adroitly dodging foliage and trees that were extremely difficult for me to see in the dim light.

After sitting at the mouth of the cave for some time, I noticed that some birds weren't as good as others at navigating in the dark. Their clicks varied much more in frequency, and occasionally I could hear them brushing against the walls of the cave. The other thing I noticed was that they came down to the entrance in very large groups. Often 10 to 20 birds would circle around in and out of the cave, and sometimes one of them would make a sortie out, but then the whole group would go back into the depths of the cave.

I speculate, although I don't have much evidence to support it, that one of the reasons they have such a long period of development is that these birds do a lot of learning. They may be acquiring this very difficult skill of building up a model of the world purely on this information from the echoes they get coming back. The large groups of birds that fly out to the mouth of the cave may be social groups where the young are being tutored in managing this very difficult task.

The second question is how they manage to see in such dim light. I was puzzled by the fact that a bird that can navigate in total darkness using echolocation should have such a good visual system—which it does. The eye is large; the aperture is very large compared to that of other birds. It's comparable to an owl's, so the oilbird's visual system is very well adapted to low levels of illumination, and this probably explains why it doesn't use the clicking means of navigation once it has a little light.

Another feature we found is that the ear recovers very quickly from a loud sound. In less than a millisecond and a half, the ear returns to its former sensitivity. This is an amazingly short recovery cycle, and presumably it would enable the bird to hear the faint echo come back very soon after it emitted a loud cry.

After the expedition was over, I was wandering around the Museo de Oro in Bogota where I saw some beautiful gold effigies of birds dating from the days of the conquistadores and before. Because these effigies have hooked beaks, weak and ineffectual feet, large wings, and long tail feathers, they are obviously likenesses of oilbirds. The figurines have spiral ear plugs just like those worn as a sign of nobility or deity among the ancient Indians. In fact, because the Inca nobility wore such large spiral ear plugs, the Spanish nicknamed them *orejones* (the Spanish word for the outer ear) to refer to their elongated ear lobes. There is also a legend about the origin of the Incas that involves a bird and these strange ear plugs.

In the light of that I was intrigued to find some artifacts in which the Indian artist chose to emphasize that feature of the oilbird that accounts for its astonishing ability to navigate in total darkness—the ears. I wonder whether our discovery that this bird has very special auditory abilities is not new at all. Perhaps some very astute Indian naturalist thousands of years ago, by observation, came to the conclusion that this bird has very sensitive hearing and perhaps even came to the conclusion that it was using echolocation to navigate in the dark. If that's so, it might explain some of the legends that are based on birds, and this custom of emphasizing the ear lobes.

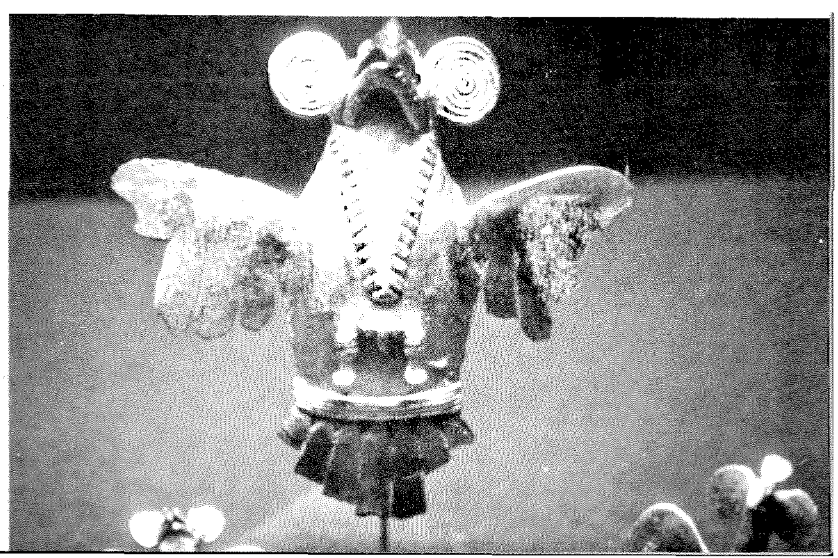
At the entrance to the cave where the oilbirds live, one specimen, stimulated by light, begins to fly horizontally—and silently—in the fashion of most other birds.

WHY HAVE FRONTALLY PLACED EYES?

There's a final puzzle about the oilbird: It has very frontally directed eyes. Most of us associate frontal vision—both eyes looking straight ahead—with an animal that hunts for its living, and this bird lives solely on fruit. It's rather hard to look at it and imagine that such a fierce character is a vegetarian, but what I've seen of it, plus some observations I've made on hawks and falcons, has led me to puzzle about this frontal-eye syndrome. The fact is that this bird has frontal vision but is not a predator, and many predators have very good binocular vision—that is, they can see very well in front of them—but they don't have their eyes pointed straight ahead. Swallows are also like this.

So let me speculate for a minute about this puzzling arangement. My theory is that the frontal arrangement of the eyes is related to the fact that birds with such an arrangement evolved to live in the nocturnal niche. It's related to the fact that the bird is adapted for night-

A golden effigy of a bird from the Museo de Oro in Bogota is almost certainly an image of an oilbird, complete with Incan spiral ear plugs indicating its auditory abilities.



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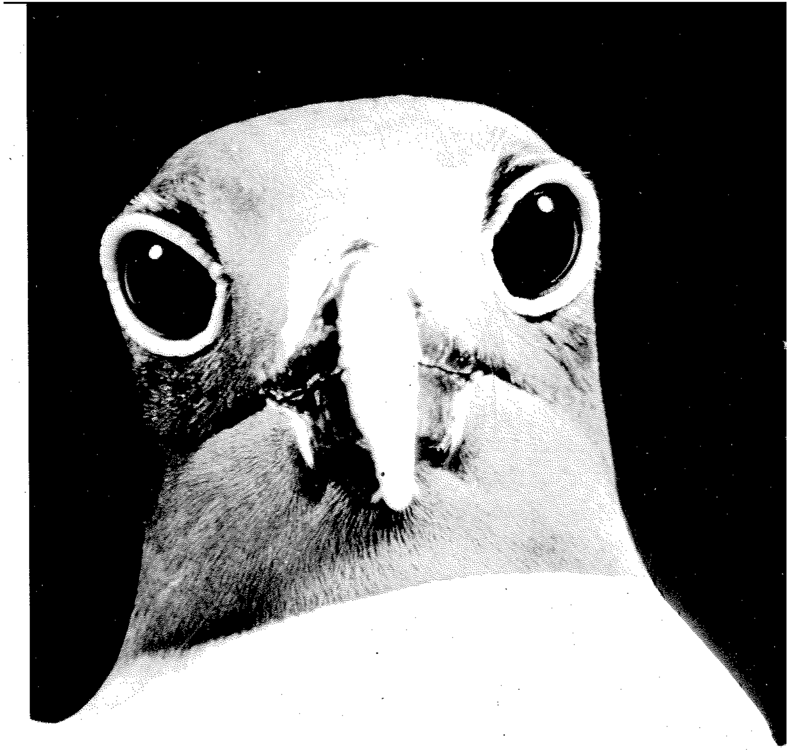


A close-up portrait of *Larus furcatus,* the nocturnal swallow-tailed seagull of the Galapagos Islands, shows its wide-aperture, frontally directed eyes—unlike those of most gulls.

time viewing. It has a region of its retina called the fovea, and that is the part of the eye directed toward objects of interest. Now the swallow, falcons, kingfishers, and hummingbirds, for example, besides having a fovea that is directed straight ahead also have a fovea that points 45 degrees off to the side. In the same eye such birds have two fovea—one looking ahead for binocular vision and one looking off to the side for peripheral vision.

If it is possible to have simultaneous frontal and peripheral vision, why is it that the owls (not to mention ourselves) have both eyes rotated forward so that both point in the same direction and there's no peripheral vision? The answer, I think, is related to the fact that in contrast to all the birds who have simultaneously good binocular vision and peripheral vision and all of whom are diurnal (that is, they are active when there's plenty of light), the owl has a visual system that is adapted for working in very low light levels. The major adaptation is the enormous aperture of the optical system—the size of the opening in comparison to the focal length.

Though these swallow-tailed seagulls have taken flight over the sea, they are too unafraid of humans for it to be likely that they were startled by the approach of Pettigrew's field assstant, Dorothy Butler.

Photographic buffs are familiar with the term "F number." Well, the owl has an F number of about one—a very fast lens. In fact, it's only recently that photographic manufacturers have been able to make a lens this fast. In contrast, the eye of the swallow has a much smaller aperture—a ratio of around two to three. One of the peculiarities of those large-aperture systems is that there are many aberrations. It's very difficult to build one of these systems that also has a wide angle because by the nature of the wide-aperture system, if rays enter away from the optical axis they tend to suffer a lot of aberrations. So if you have a large-aperture eye, adapted for working in low-level light, you may be forced to point that eye in the same direction from which you're getting the visual information. It may not be possible to look simultaneously in two directions with high accuracy. My prediction is that the frontalization of the eye that we saw in the oilbird and that is shared by the owl (and by us) is related to adaptation for the nocturnal niche.

A NATURAL EXPERIMENT

This is a nice theory, but how does one go about testing it? For what is known as a natural experiment, we should look for two closely related birds, one of which is nocturnal and the other a daytime bird. I talked to some ornithologists who told me that down in the Galapagos Islands there is a nocturnal seagull. Most seagulls, of course, are diurnal, and they have laterally placed eyes for peripheral vision. Without having seen this seagull in the Galapagos, I predicted that it would have more frontally placed eyes. Checking my prediction gave me an excuse to go off to the Galapagos Islands last summer. This nocturnal, swallow-tail gull is one of the very interesting adaptations that Darwin missed.

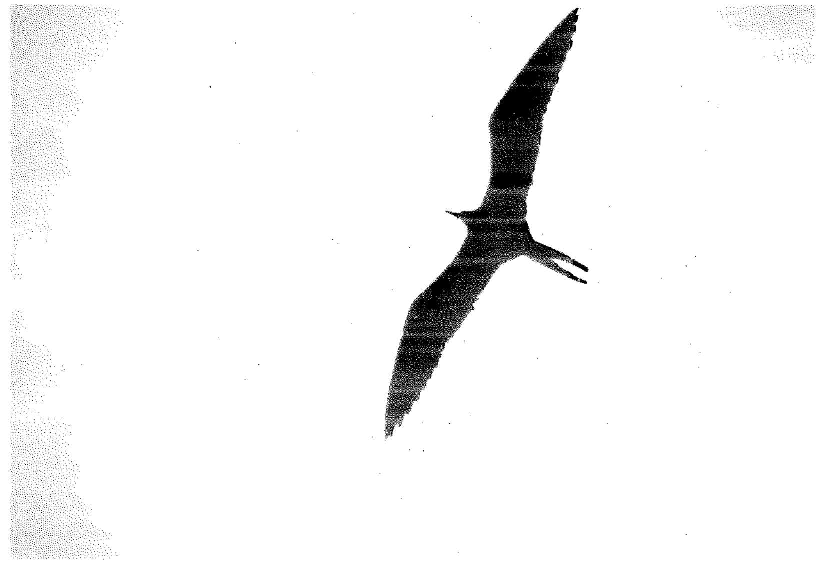
The Galapagos are on the equator about 600 miles from the coast of Ecuador. A plane goes there a few times a week from Guayaquil, and since there are about 60 islands in the archipelago, you have to choose which one you want to go to. I chose Genovesa, also called Tower, which is not a very good name because it's a very flat island. It's so flat that the fishermen who take you there refuse to start if there's any chance of arriving after dark. They're afraid they'll miss the thing and go heading off to Panama.

The Galapagos Islands are extremely inhospitable. Tower is rocky, harsh, and hot. I could only work in the early morning and the late evening. There are lots of fresh, sharp lava beds and lots of cactus. Despite its inhospitable nature, Tower is a paradise of wild life, and all the birds are very tame. It's literally possible to catch them by hand. To take photographs of their eyes, I just walked up to them, talking sweetly, and caught them. So even a rank amateur like myself can get quite passable pictures of these birds.

On Tower the bird I wanted to study is present in a colony of thousands. It's called *Larus furcatus,* which refers to its forked tail—a nocturnal, swallow-tailed gull. During the daytime these birds are in evidence all around the island. They hang around their nest sites, or congregate around the headland. They are rather beautiful birds—a little larger than the usual seagulls one sees around the California coast. When the nest site is approached, they give a characteristic alarm call and fly in a circle and come back and land on the nest. The reason they stay home all day is that they're protecting their nests from the real villain—the frigate bird.

The frigate bird has a wingspan of about 7 feet and weighs about a pound. It has the lightest wing loading of any bird; it's a master flier—and it's also a villain. I couldn't help getting a little paranoid about this bird because I arrived on the island a little bit seasick and a little sunstroked, and these birds, with their vicious hooked bills, filled the sky. They were soaring around all day, and their huge black shadows swept across the island, giving me visions of those nasty flying beasts in Tolkien's *Lord of the Rings*—the Nazgûls.

This sounds like a delusional vision, but it was confirmed when one of these birds, as I was watching it, grabbed hold of the little pink foot of a booby who was returning after a couple of days of hard work getting fish for its young. As the booby was flying in, this frigate bird gave a few tweaks on the booby's foot. It does this because it wants to hear what kind of a noise the booby makes. If the booby makes a loud noise of protest, it means it has an empty crop. If the noise of protest is rather more muffled, that's a sign that the crop is full, and then the frigate birds get to work on the fellow. Eventually, if he does have a full crop, he regurgitates it and crash-lands in the water. Then the frigate birds, completely effortlessly, drop down and before the food hits the water, they snap it up with their long bills.



A master flier, the frigate bird is also a master predator, who steals both food and baby birds from the gulls and boobys that nest in the Galapagos.

I've painted an overly harsh picture of these frigate birds. It's true that they do go catch flying fish for themselves, and they're remarkable both for their visual ability and their aerodynamic ability. They have a visual system similar to that of the swallow, with the laterally placed diurnal eye. Certainly, when the sun goes down, this bird clears from the sky immediately and goes to roost. The reason I overly stressed the villainous piracy of the frigate birds is that it is the probable explanation for the evolutionary pressure that has driven the swallow-tailed gull to become a noc-

The nocturnal seagull is one of the inhabitants of the Galapagos Islands that Darwin missed. These two specimens keep a wary watch for the rapacious frigate bird.

turnal forager. It stays home all day to protect the nest, and on many occasions we watched frigate birds try to take the chick from a nesting gull. Then at night, when the frigate birds have gone to bed, the gulls go off and forage.

More questions arise as to how they can manage to forage at night. They do have a very large eye; in fact, it is comparable to that of the oilbird, which is comparable to the eye of a barn owl. Like an owl they have an eye with an F number of about one. It's much faster than the eye of other seagulls. Still, I was puzzled about how they could hunt on a very dark night. I was puzzled because the other birds I've mentioned—for example, the owl—get a lot of help from other cues. Owls can hear their prey rustling, and they have acute auditory systems that enable them to catch prey even if there is no light at all. The oilbird, similarly, has a very good nose and is able to track down foods partly by olfaction.

I wondered about what help this bird might get, and I think the answer was provided by the fact that the Galapagos, like many tropical waters, have a large amount of bioluminescence. If you go swimming at night, and you move your hands under the water, you can create beautiful patterns because the marine organisms luminesce as they are disturbed. And if one examines the contents of the crops of these birds when they come back from a hunting expedition, mixed in with the squid and fish they've taken are many of the luminescent organisms. So it's possible that they get a lot of help in tracking their prey at night by the track that is left by fish streaking through the water and disturbing the phosphorescent organisms.

But how about my prediction? I went all the way to the Galapagos to test this prediction I had made that if a bird is nocturnally adapted, it should have more frontally directed eyes than a diurnal close relative. I took pictures of the inside of the eye. I made some measurements. But I think all of these are just incidental confirmation of the fact that this seagull's visual system is rather owl-like. It has frontally directed eyes, in comparison with other seagulls. So it was very gratifying to me to enjoy this adventurous expedition and at the same time to come up with a finding that verified my prediction. There is a link between frontalization of the eyes and the nocturnal niche.

That's one natural experiment where my theory was vindicated, but where will I go to next? Can I find any more? It turns out there is a very nice natural experiment one could do in New Zealand. There's a nocturnal parrot that's called the kakapo, or owl parrot. You can guess from the name that this parrot has very frontally directed eyes in comparison with other parrots. In fact, one of the first people to study this bird asserted that it was indeed an owl rather than a parrot with very frontal eyes. Unfortunately, it is an endangered species; not many have been seen in this century. But I have corresponded with a few people in New Zealand who have seen them, and it appears that the prediction also holds that the kakapo has much more frontally directed eyes than his close diurnal relatives.

This observation that there's a link between the nocturnal niche and frontalization of the eyes has some other implications in the way the brain is organized, because the visual pathways of a frontally eyed beast are different from those of a laterally eyed beast. It's for this reason that the statements I've been making have a little relevance to understanding our own visual system. We might ask the same question. Is it possible that there's any relationship between the human or primate condition—having both eyes frontal and looking in the same direction—and the nocturnal niche?

I think the answer is possibly yes, and the reason for this is (and most paleontologists would agree now) that the first primate—the first member of the line that gave rise to man—was a nocturnal mammal. The fossils of the first primate look very similar to the skull of a beast called the tarsier, a tropical animal found in Southeast Asia. It has a rather owl-like face—very frontally directed eyes—and there is much agreement that the primate line began with a beast like this. It is extremely nocturnal; it doesn't come out in the daytime at all. It's a predator that catches its prey at night.

I guess the point I'm making is that in getting some insight into the frontal-eye syndrome and its relationship to nighttime vision, I may help solve some of the puzzles about our own condition.

In conclusion, then, I hope I've given you some feeling for the way in which the zoological ferment of the tropics has influenced me in my thinking about vision and further influenced me to put this thinking into a broader evolutionary context. My proposal that the frontal position of the eyes could be related to the nocturnal adaptation has many ramifications and, of course, many prospects for exciting trips. It's also possible that it may lead to some elucidation of some of the puzzles about our own visual system. □