SPILLOVER

Animal Infections and the Next Human Pandemic

DAVID QUAMMEN

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IV

DINNER AT THE RAT FARM

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In late February 2003, SARS got on a plane in Hong Kong and went to Toronto.

Its arrival in Canada was unheralded but then, within days, it began to make itself felt. It killed the seventy-eight-year-old grandmother who had carried it into the country, killed her grown son a week later, and spread through the hospital where the son had received treatment. Rather quickly it infected several hundred other Toronto residents, of whom thirty-one eventually died. One of the infected was a forty-six-year-old Filipino woman, working in Ontario as a nursing attendant, who flew home to the Philippines for an Easter visit, started feeling sick the day after arrival (but remained active, shopping and visiting relatives), and began a new chain of infections on the island of Luzon. So SARS had gone halfway around the world and back, in two airline leaps, over the course of six weeks. If circumstances had been different—less delay on the ground in Toronto, an earlier visitor headed from there to Luzon or Singapore or Sydney—the disease could have completed its global circuit far more quickly.

To say that "SARS got on a plane," of course, is to commit metonymy and personification, both of which are forbidden to the authors of scientific journal articles but permissible to the likes of me. And you know what I mean: that what actually boarded an

airplane in each of those cases was an unfortunate woman carrying some sort of infectious agent. The seventy-eight-year-old Toronto grandmother and the younger nursing attendant remain anonymous in the official reports, identified only by age, gender, profession, and initials (like BW the malarious surveyor), for reasons of medical privacy. As for the agent—it wasn't identified and named until weeks after the outbreak began. No one could be sure, at that early stage, whether it was a virus, a bacterium, or something else.

In the meantime it had also arrived in Singapore, Vietnam, Thailand, Taiwan, and Beijing. Singapore became another epicenter. In Hanoi, a Chinese American businessman who brought his infection from Hong Kong became ill enough to merit examination by Dr. Carlo Urbani, an Italian parasitologist and communicable-diseases expert stationed there for the World Health Organization. Within ten days the businessman was dead; within a month, Dr. Urbani was too. Urbani died at a hospital in Bangkok, having flown over for a parasitology conference in which he was never able to take part. His death, because of his much-admired work within WHO, became a signal instance of what emerged as a larger pattern: high rates of infection, and high lethality, among medical professionals exposed to this new disease, which seemed to flourish in hospitals and leap through the sky.

It reached Beijing by at least two modes of transport, one of which was China Airlines flight 112, from Hong Kong, on March 15. (The other route into Beijing was by car, when a sick woman drove up from Shanxi province seeking better treatment in the national capital; how she had become infected, and whom she infected in turn, is a different branch of the story.) Flight CA112 took off from Hong Kong that day carrying 120 people, including a feverish man with a worsening cough. By the time it landed in Beijing, three hours later, twenty-two other passengers and two crewmembers had received infectious doses of the coughing man's germs. From them it spread through more than seventy hospitals just in Beijing—yes, *seventy*—infecting almost four hundred health-care workers as well as other patients and their visitors.

Around the same time, officials at WHO headquarters in Geneva

issued a global alert about these cases of unusual pulmonary illness in Vietnam and China. (Canada and the Philippines weren't mentioned because this was just before their involvement was recognized.) In Vietnam, said the statement, an outbreak had begun with a single patient (the one Carlo Urbani examined) who was "hospitalized for treatment of severe, acute respiratory syndrome of unknown origin." The little comma after "severe" reflects the fact that those three adjectives and one noun hadn't yet been codified into a name. Several days later, as the pattern of hopscotching outbreaks continued to unfold, WHO issued another public statement of alarm. This one, framed as an emergency travel advisory, marked the transformation of a descriptive phrase into a label. "During the past week," it said, "WHO has received reports of more than 150 new suspected cases of severe acute respiratory syndrome (SARS), an atypical pneumonia for which cause has not yet been determined." The advisory quoted WHO's director-general at the time, Dr. Gro Harlem Brundtland, speaking starkly: "This syndrome, SARS, is now a worldwide health threat." We had all better work together, Brundtland added (and do so quickly, she implied), to find the causal agent and stop its spread.

Two aspects of what made SARS so threatening were its degree of infectiousness—especially within contexts of medical care—and its lethality, which was much higher than in familiar forms of pneumonia. Another ominous trait was that the new bug, whatever it might be, seemed so very good at riding airplanes.

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Hong Kong wasn't the origin of SARS, merely the gateway for its international dispersal . . . and very *close* to its origin. The whole phenomenon had begun quietly, several months earlier, in the southernmost province of mainland China, Guangdong, a

place of thriving commerce and distinctive culinary practices, to which Hong Kong is attached like a barnacle to the belly of a whale.

Once a British colony, Hong Kong in 1997 was subsumed into the People's Republic of China—but subsumed on a special basis, retaining its own legal system, its capitalist economy, and a degree of political autonomy. The Hong Kong Special Administrative Region, which includes Kowloon and other mainland districts as well as Hong Kong Island and several other islands, shares a border with Guangdong and a fluid exchange of visitors and trade. More than a quarter million people cross that border by land travel every day. Despite the easy commercial relations and visiting privileges, though, there's not much direct contact between Hong Kong officialdom and Guangdong's provincial capital, Guangzhou, a city of 9 million people that sits about two hours by road from the crossing. Political communications are filtered through the national government in Beijing. That constraint applies also, and unfortunately, to the scientific and medical institutions in both places—such as Hong Kong University, with its excellent medical school, and the Guangzhou Institute of Respiratory Diseases. Lack of basic communication, let alone resistance to collaborative work and sharing of clinical samples, caused problems and delays in responding to SARS. The problems were eventually solved but the delays were consequential. When the infection first crossed the border, from Guangdong to Hong Kong, very little information crossed with it.

Guangdong is drained by the Zhu (Pearl) River, and the whole coastal area encompassing Hong Kong, Macau, Guangzhou, and a new border metropolis called Shenzhen, as well as Foshan, Zhongshan, and other surrounding cities, is known in English as the Pearl River Delta. On November 16, 2002, a forty-six-year-old man in Foshan came down with fever and respiratory distress. He was the first case of this new thing, so far as epidemiological sleuthing can determine. No samples of his blood or mucus were later available for laboratory screening, but the fact that he triggered a chain of other cases (his wife, an aunt who visited him in the hospital, the aunt's husband and daughter) strongly suggests that SARS was what he had. His name too goes unmentioned, and he has been

described simply as a "local government official." The only salient aspect of his profile, in retrospect, is that he had helped prepare some meals, of which the ingredients included chicken, domestic cat, and snake. Snake on the menu wasn't unusual in Guangdong. It's a province of ravenous, unsqueamish carnivores, where the list of animals considered delectable could be mistaken for the inventory of a pet store or a zoo.

Three weeks later, in early December, a restaurant chef in Shenzhen fell ill with similar symptoms. This fellow worked as a stir-fry cook, and though his tasks didn't include killing or gutting wild animals, he would have handled their chopped and diced pieces. Feeling sick in Shenzhen, he commuted home to another city, Heyuan, and sought medical treatment there at the Heyuan City People's Hospital, where he infected at least six health-care workers before being transferred to a hospital in Guangzhou, about 130 miles to the southwest. One young doctor who rode to Guangzhou in the ambulance with him also became infected.

Not long afterward, during late December and January, other such illnesses started occurring in Zhongshan, sixty miles south of Guangzhou and just west across the Pearl River Delta from Hong Kong. Within the next several weeks, twenty-eight cases were recognized there. Symptoms included headache, high fever, chills, body aches, severe and persistent coughing, coughing up bloody phlegm, and progressive destruction of the lungs, which tended to stiffen and fill with fluid, causing oxygen deprivation that in some cases led to organ failure and death. Thirteen of the Zhongshan patients were health-care workers and at least one was another chef, whose bill of fare included snakes, foxes, civets (smallish mammals, distantly related to mongooses), and rats.

Authorities at Guangdong's provincial health bureau noticed the Zhongshan cluster and sent teams of "experts" to help with treatment and prevention, but nobody was really an expert, not yet, on this mystifying, unidentified disease. One of those teams prepared an advisory document on the new ailment, labeling it "atypical pneumonia" (*feidian* in Cantonese). That was the phrase, a common though vague formulation, used weeks later by WHO

in its global alert. An atypical pneumonia can be any sort of lung infection not attributable to one of the familiar agents, such as the bacterium *Streptococcus pneumoniae*. Applying that familiar label tended to minimize, not accentuate, the uniqueness and potential severity of what was occurring in Zhongshan. This "pneumonia" was not just atypical; it was anomalous, fierce, and scary.

The advisory document, which went to health offices and hospitals throughout the province (but was otherwise kept secret), also supplied a list of telltale symptoms and recommended measures for controlling against wider spread. Those recommendations were too little and too late. At the end of the month, a seafood wholesaler who had recently visited Zhongshan checked into a Guangzhou hospital and triggered the chain of infections that would circle the world.

This seafood merchant was a man named Zhou Zuofeng. He holds the distinction of being the first "superspreader" of the SARS epidemic. A superspreader is a patient who, for one reason or another, directly infects far more people than does the typical infected patient. While R_0 (that important variable introduced to disease mathematics by George MacDonald) represents the average number of secondary infections caused by each primary infection at the start of an outbreak, a superspreader is someone who dramatically exceeds the average. The presence of a superspreader in the mix, therefore, is a crucial factor in practical terms that might be overlooked by the usual math. "Population estimates of R_0 can obscure considerable individual variation in infectiousness," according to J. O. Lloyd-Smith and several colleagues, writing in the journal *Nature*, "as highlighted during the global emergence of severe acute respiratory syndrome (SARS) by numerous 'superspreading events' in which certain individuals infected unusually large numbers of secondary cases." Typhoid Mary was a legendary superspreader. The significance of the concept, Lloyd-Smith and his coauthors noted, is that if superspreaders exist and can be identified during a disease outbreak, then control measures should be targeted at isolating those individuals, rather than applied more broadly and diffusely across an entire population. Conversely, if

you quarantine forty-nine infectious patients but miss one, and that one is a superspreader, your control efforts have failed and you face an epidemic. But this useful advice was offered from hindsight, in 2005, too late for application to the fishmonger Zhou Zuofeng in early 2003.

No one seems to know where Mr. Zhou picked up his infection, though presumably it wasn't from seafood. Fish and marine crustaceans have never been implicated among the possible reservoirs for the pathogen causing SARS. Zhou ran a shop in a major fish market, and possibly his sphere of activities intersected with other live markets, including those that offered domestic and wild birds and mammals. Whatever its source, the infection took hold, went to his lungs, caused coughing and fever, and drove him to seek help at a Guangzhou hospital on January 30, 2003. He remained at that hospital only two days, during which he infected at least thirty health-care workers. His condition worsening, he was transferred to a second hospital, a place that specialized in handling cases of atypical pneumonia. Two more doctors, two nurses, and another ambulance driver were infected during his transfer, as Zhou gasped for breath, vomited, and spattered phlegm around the ambulance. At the second hospital he was intubated to save him from suffocation. That is, a flexible tube was inserted deep into his mouth, past his glottis, and down his windpipe into his lungs, to help with breathing. This event represents another important clue toward explaining how SARS spread so effectively through hospitals around the world.

Intubation is a simple procedure, at least in theory, but it can be difficult to execute amid the gag reflexes, sputters, and expectorations of the patient. The task was especially hard with Zhou, a portly man, sedated and feverish, and though his disease hadn't yet been identified, the attending doctors and nurses seem to have had some sense of the danger to which they were being exposed. They knew by then that this atypical pneumonia, this whatever, was more transmissible and more lethal than pneumonias of the common sort. "Each time they began to insert the tube," according to an account by Thomas Abraham, a veteran foreign correspondent

based in Hong Kong, there was "an eruption" of bloody mucus. Abraham continues:

> It splashed on to the floor, the equipment and the faces and gowns of the medical staff. They knew the mucous [*sic*] was highly infectious, and in the normal course of things, they would have cleaned themselves up as quickly as possible. But with a critically ill patient kicking and heaving around, a tube half-inserted into his windpipe and mucous and blood spurting out, there was no way any of them could leave.

At that hospital, twenty-three doctors and nurses became infected from Zhou, plus eighteen other patients and their relatives. Nineteen members of his own family also got sick. Zhou himself would eventually become known among medical staff in Guangzhou as the Poison King. He survived the illness, though many people who caught it from him—directly, or indirectly down a long chain of contacts—did not.

One of those secondary cases was a sixty-four-year-old physician named Liu Jianlun, a professor of nephrology at the teaching hospital where Zhou had first been treated. Professor Liu began feeling flulike symptoms on February 15, two weeks after his exposure to Zhou, and then seemed to get better—well enough, he thought, to follow through on plans to attend his nephew's wedding in Hong Kong. He and his wife took the three-hour bus ride from Guangzhou on February 21, crossed the border, spent an evening with family, and then checked into a large, midrange hotel called the Metropole, favored by businessmen and tourists, in the Kowloon district of Hong Kong. They were given room 911, across from the elevators in the middle of a long corridor, a fact that became central to later epidemiological investigations.

Two fateful things happened that night at the Metropole Hotel. The professor's condition worsened; and at some point he seems to have sneezed, coughed, or (depending on which account you believe) vomited in the ninth-floor corridor. In any case, he shed a sizable dose of the pathogen that was making him sick—enough

to infect at least sixteen other guests and a visitor to the hotel. Professor Liu thereby became the second known superspreader of the epidemic.

Among the hotel guests sharing floor nine was a seventy-eight-year-old grandmother from Canada. I mentioned her earlier. She had come to visit family and then spent several nights at the Metropole, along with her husband, as part of an airline-hotel package. Her room was 904, just across the corridor and a few steps down from Professor Liu's. Her stay overlapped with his presence for only one night—the night of February 21, 2003. Maybe they shared a ride on the elevator. Maybe they passed in the hallway. Maybe they never laid eyes on each other. No one knows, not even the epidemiologists. What's known is that, the next day, the professor awoke feeling too sick to attend any wedding and instead checked himself into the nearest hospital. He would die on March 4.

One day after Professor Liu left the Metropole, the Canadian grandmother left too, having finished her Hong Kong visit. Infected but not yet symptomatic, and presumably feeling fine, she boarded her flight home to Toronto, taking SARS global.

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Another route of international dispersal from the Metropole Hotel led to Singapore, when a young woman named Esther Mok returned from a shopping vacation in Hong Kong, feeling feverish. That was February 25. For the previous four nights, she and a female friend had shared room 938 at the Metropole, about twenty steps from Professor Liu's room.

Back home in Singapore, Mok's fever lingered and she developed a cough. On March 1 she consulted doctors at Tan Tock Seng Hospital, a large public facility housed in gleaming new buildings just north of the city center. After a chest X-ray showed white

patches on her right lung, Mok was admitted under a diagnosis of atypical pneumonia. One of the doctors who saw her was Brenda Ang, a senior consultant for infectious diseases, who happened also to be in charge of infection control at Tan Tock Seng. There was no particular alarm about infection control, though, when Esther Mok brought her condition to the hospital. "At that time," Brenda Ang told me later, "we didn't know what it was."

Ang agreed to take me through the story from memory, half a dozen years after the events, and though she warned that her recollections might be patchy, on many points they seemed rather precise. We met in a conference room within a small, detached structure on the landscaped grounds of Tan Tock Seng; it was a room that served intermittently for staff meetings and as a classroom for medical students on rounds, but we had it for an hour. Ang was a tiny, forthright woman in a lilac print dress. Observing medical discretion, she didn't use Esther Mok's name but spoke instead of "a young lady" who had been "the first index case." In her role as infectious disease consultant, Dr. Ang had seen the first index case herself. She was assisted by her registrar (a younger doctor in specialty training), who took a mucus sample from Mok for culturing. The registrar wasn't wearing a mask, Ang told me. No one at Tan Tock Seng was masked against this infection at the start, but unlike Ang herself, the registrar got sick.

His case, with some dramatic complications, unfolded later. In the meantime, Ang and her colleagues dealt with Esther Mok's worsening pneumonia, unaware that the young woman was becoming another superspreader of this disease that had not yet been identified or named.

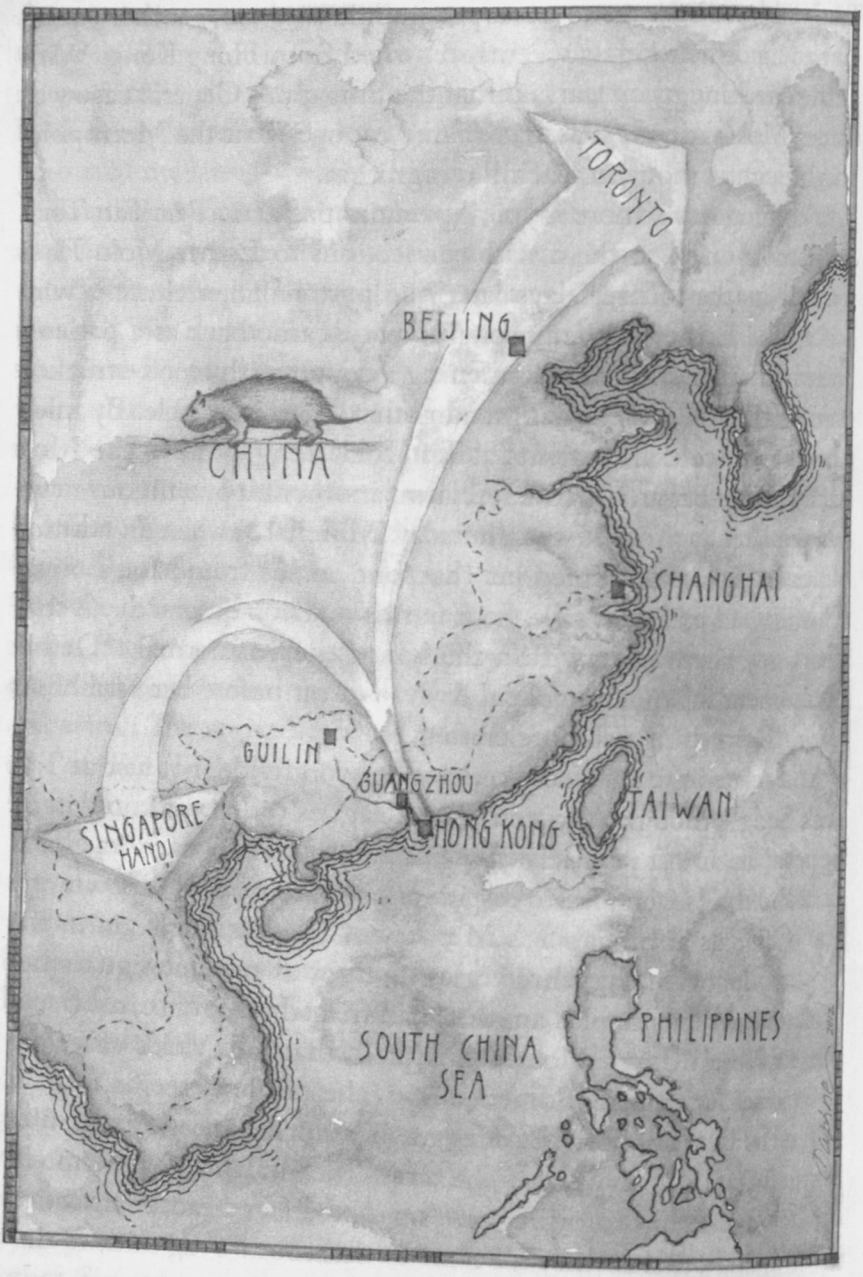
At first Mok was placed in an open ward, with closely spaced beds, in proximity to other patients and staff members coming and going. After a few days, now gasping for air, she was transferred to the Intensive Care Unit. It seemed unusual, Ang told me, for such a young person to be struck by pneumonia so severely—unusual enough that, on the Friday of that week, when doctors from the other Singapore hospitals visited Tan Tock Seng for weekly grand rounds, Ang and her colleagues presented the atypical pneumonia

case for discussion. Having heard the symptoms and the history, one doctor from Singapore General Hospital spoke up, saying, That's odd, we have an atypical pneumonia case too, another young woman, and she too has recently returned from Hong Kong. With a little checking, they learned that the Singapore General case was Esther Mok's friend, who had shared room 938 at the Metropole. This brought a moment of chill recognition.

In coming days, more atypical pneumonias arrived at Tan Tock Seng, most or all of them with connections to Esther Mok. First was her mother. Three days later, the pastor of her church, who had visited Esther at the hospital to pray, came back as a patient. Then her father showed up, suffering a cough with blood-streaked sputum. Then her maternal grandmother, then her uncle. By mid-month they were all patients at Tan Tock Seng. And as the Mok family cluster began to generate alarm, another bit of ominous news reached Brenda Ang. It was Thursday, March 13, when an administrative assistant informed her that four nurses from Mok's original ward had called in sick. Four nurses out sick on one day—that wasn't anywhere near within the boundaries of normal. "Defining moment for me," Ang said dryly, as I sat before her scribbling notes. "Everything was accelerating."

And related events were accelerating worldwide, not just at Tan Tock Seng—though Ang and her colleagues didn't yet know it. In Geneva, at almost precisely the same time, WHO issued its global alert about a "severe, acute respiratory syndrome of unknown origin." Officials at Singapore's Ministry of Health were soon in the loop, made aware that three cases of atypical pneumonia (Esther Mok and her friend, plus another) had turned up at once, all traceable to Hong Kong's Metropole Hotel. That put Mok's case into a much larger picture. Someone from the ministry seems to have called the CEO of Tan Tock Seng, whereupon a meeting of senior hospital staff was convened. The CEO, the chairman of the medical board, the nursing director, Ang herself as head of infection control, and others—they all came to this room, Ang said, to discuss what was happening.

"Came to *this* room?" I asked.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"This room," she said. "Same room." That's when the CEO told them: "I think we've got an outbreak on our hands. And we need to organize."

A doctor named Leo Yee Sin, with previous experience of handling a Nipah outbreak, was charged with mobilizing special measures of response. The Ministry of Health advised Tan Tock Seng's leadership: Get ready to accept cases, because we're starting to see more—friends and relatives of the first group, now showing symptoms. Leo Yee Sin got people moving. They set up a tent outside one ward, for screening patients, and brought down an X-ray machine to check possible cases for lung involvement. Most of the patients were admitted to general wards, but the sicker ones went to Intensive Care. As the first Intensive Care Unit filled up, two others were converted into SARS ICUs, exclusively for handling additional cases. Isolation and barrier nursing were important control measures, though Ang and her colleagues still didn't know what they were isolating. "Remember," she told me, "all this time there are no diagnostic tests." No tests, she meant, that detected presence or absence of the culpable infectious agent—because no one had yet identified that agent. "We are going purely based on epidemiology—whether there is contact with some of the source patients." It was blind man's bluff.

On Friday of that week, March 14, the hospital's annual dinner and dance, long planned and anticipated, would occur at the Westin Hotel. It went ahead as scheduled, more or less, although Brenda Ang and some colleagues sat at half-empty tables wondering, Where's Leo Yee Sin, where's this colleague, where's that one? Well, they were absent in extremis—back at the hospital, shifting beds and other furniture to put the place on an emergency footing. Ang herself rejoined the scramble on Saturday morning.

In her capacity as head of infection control, Ang started getting all staff members into gowns, gloves, and high-filtration N95 masks, the kind that fit more snugly than mere surgical masks. But she faced a shortage of those supplies, and then also black-market inflation; N95 masks in Singapore went from $2 to $8 apiece. Still, they were doing the best that could be done. On March 23, by

which point the disease had an internationally recognized name, Tan Tock Seng became the designated SARS hospital for Singapore, with all patients to be transferred there from other hospitals. Visitation was restricted. Staff members were masked, gloved, and gowned.

Before the isolation and protection measures were fully implemented, though, another superspreader event occurred, this one in the hospital's Coronary Care Unit. A middle-aged woman with multiple health problems, including diabetes and heart disease, had been admitted to one of the open wards; she was infected there by a health-care worker, who had in turn been infected by Esther Mok. Then the older woman suffered a heart attack and was moved to the CCU. Her atypical pneumonia symptoms hadn't yet manifested—not enough, anyway, to be weighed against her coronary crisis. In the CCU she was intubated by the attendant cardiologist, with assistance from a cardiology resident. Again, as with the Poison King in Guangzhou, intubation seems to have been an occasion for transmission. Eventually twenty-seven people became infected in the CCU, including five doctors, thirteen nurses, one ultrasound technician, two cardiac technicians, one attendant, and five visitors. I found that tally in a later report. Brenda Ang's account was more personal. She recollected that the cardiologist, a pregnant woman, had worn a mask while performing the intubation, and though that doctor got ill afterward, she recovered. The resident, standing nearby, had worn no mask. "It was a guy. He was sick for a while and brought it home. His mother," Ang said. "His own mother nursed him and *she* became sick."

"Did they survive?"

"No."

"Neither one of them," I said.

"It was one of the most painful things. Because he was a young, twenty-seven-year-old doctor. And his mother also died."

Another young doctor who faced similar exposure was Brenda Ang's registrar—remember him?—who had taken a throat swab from Esther Mok. His story reflects the dawning awareness that this syndrome was caused by some highly infectious bug, maybe

a bacterium, maybe a virus, which spread readily through face-to-face contact, especially in crowded or intimate circumstances. Days after assisting Ang with her examination of Mok, the registrar boarded a plane. He flew to an infectious-disease conference in New York, twenty hours' worth of air travel from Singapore, and was there when he began feeling sick. Before embarking to come home, via Frankfurt, he phoned a colleague in Singapore and mentioned that he was ill. The colleague alerted Singaporean authorities, who alerted WHO, who alerted German officials, who met the plane when it landed in Frankfurt and took the doctor away into quarantine. He spent almost three weeks in a Frankfurt hospital, along with his wife and his mother-in-law, who by then were sick too. One crewmember from the plane, but only one, had also been infected. Unlike the cardiology resident who assisted the intubation, though, these patients in Frankfurt all survived.

Back in Singapore, health officials and government authorities cooperated to stanch further transmission. They enacted firm measures that reached far beyond the hospitals—such as enforced quarantine of possible cases, jail time and fines for quarantine breakers, closure of a large public market, school closures, daily temperature checks for cab drivers—and the outbreak was brought to an end. Singapore is an atypical city, firmly governed and orderly (that's putting it politely), therefore especially capable of dealing with an atypical pneumonia, even one so menacing as this. On May 20, 2003, eleven people were taken to court and fined $300 each for spitting.

By the middle of July, when the last SARS patient left Tan Tock Seng Hospital, more than two hundred cases had been recognized. Thirty-three of those people died, among whom were Esther Mok's father, her pastor, her mother, and her uncle, in that order of demise. Esther herself survived.

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Dead or recovered, they had all been infected—but infected with *what*?

As the disease spread internationally, scientists on three continents worked in their laboratories with samples of tissue, blood, mucus, feces, and other vital, unsavory materials taken from one patient or another, trying to isolate and identify a causal agent. The very name coined during that early period, SARS, reflects the fact that this thing was known only by its effects, its impacts, like the footprints of a large, invisible beast. Ebola is a virus. Hendra is a virus. Nipah is a virus. SARS is a syndrome.

The search for the SARS pathogen proceeded urgently in those laboratories, but it was hampered by some confusing signals and false leads. For starters, the symptoms looked a little bit too much like influenza—or, more precisely, like influenza at its worst. One form of influenza at its worst is the so-called bird flu, caused by a virus designated as H5N1, with which Hong Kong in particular had had fearful experience just half a dozen years earlier, when eighteen people became infected by spillovers from domestic poultry. Eighteen doesn't sound like a large number of patients; the fearful aspect was that six of those eighteen died. Health authorities had responded quickly, ordering the closure of live poultry markets and the destruction of every chicken in Hong Kong—amounting to 1.5 million doomed, squawking birds—followed by a seven-week hiatus for decontamination. This draconian response, combined with the fact that H5N1 didn't transmit well from human to human, only from bird to human, had succeeded in ending the 1997 Hong Kong outbreak. But in February 2003, just when alarming rumors about "a strange contagious disease" began to emerge by email and text message from Guangdong, avian flu struck again in Hong Kong. It was entirely distinct from the SARS outbreak, but that couldn't easily be seen at the time.

The flu killed a thirty-three-year-old man and sickened (but didn't kill) his eight-year-old son. It probably also killed the man's seven-year-old daughter, who had died two weeks earlier of a

pneumonia-like illness during a family visit to Fujian, the Chinese province just northeast of Guangdong. Possibly the little girl had consorted too closely with Chinese chickens; her brother had definitely done that, according to his own later testimony. Samples of nasal mucus from both the father and the son showed positive for H5N1, which seemed to suggest that the wider flurry of case reports from Guangdong might likewise pertain to avian flu. So the scientists tested their SARS samples for H5N1. But that was a false lead.

Another wrong notion was that SARS might be caused by some form of chlamydia, a diverse group of bacteria that includes two kinds associated with respiratory disease in humans (as well as another, more famous among teenagers, that's sexually transmitted). One of the respiratory chlamydias is zoonotic, leaping from birds (notably, pet parrots) into humans. During late February, a very senior Chinese microbiologist found what looked like chlamydia in some SARS specimens and, based on his tenuous evidence—also, his august standing in the respectful milieu of Chinese science—the chlamydia hypothesis was embraced overconfidently by high health officials in Beijing. At least one other eminent Chinese researcher dissented, arguing that, if a chlamydia was the cause, SARS cases should have responded to treatment with antibiotics—which they did not. But that fellow was down in Guangdong, at the Institute for Respiratory Diseases, and Beijing didn't want to hear him.

The laboratory scientists meanwhile explored other possibilities too, quite a list: plague, spotted fever, Legionnaires' disease, typhus, several kinds of bacterial pneumonia, seasonal influenza, *E. coli* in the blood, Old and New World hantaviruses, and more. Part of what made the task difficult was that, in pursuing the SARS agent, they didn't know whether they were looking for something familiar, something newish but closely resembling something familiar, or something entirely new.

And there was one other possible category: something familiar to veterinarians but entirely new as an infection of humans. In other words, an emerging zoonosis.

The sorts of lab methodology I've described earlier, involving

PCR to screen for recognizable fragments of DNA or RNA, combined with molecular assays to detect antibodies or antigens, are useful only in searching for what's familiar—or, at least, for what closely resembles something familiar. Such tests essentially give you a positive, negative, or approximated answer in response to a specific question: Is it *this*? Finding an entirely new pathogen is more difficult. You can't detect a microbe by its molecular signature until you know roughly what that signature is. So the lab scientist must resort to a slightly older, less automated approach: growing the microbe in a cell culture and then looking at it through a microscope.

At the University of Hong Kong, high on the side of a peak overlooking the downtown neighborhoods, a team led by Malik Peiris took this approach to its fruitful conclusion. Peiris is an Oxford-educated microbiologist, born and raised in Sri Lanka, soft-spoken and judicious, with fine dark hair that hugs his skull roundly. He is known primarily as an influenza researcher and, having come to Hong Kong in 1995, just before the big bird-flu scare, he had reason to consider avian influenza as a leading hypothesis for what was now coming out of Guangdong. "The first thing going through our minds was that the H5N1 virus had possibly acquired the ability to transmit from human to human," he told a reporter in 2003. But after testing their SARS samples for H5N1, as well as for a roster of the usual suspects, and finding no evidence of any, his team moved toward the idea that they were dealing with a new virus.

They focused then on trying to culture it. This meant, first of all, giving the mystery creature an environment of living cells in which it was able to replicate, until it grew abundant enough in the culture, and caused enough damage to the cells, that its presence could be seen. The living cells of the culture had to be one or another "immortalized" lineage (such as the famous HeLa cells from an unfortunate woman named Henrietta Lacks), so that they would continue replicating indefinitely until something killed them. Peiris's team began by offering the new bug five different cell lines that had variously proven hospitable to familiar respiratory pathogens: cells from a dog's kidney, cells from a rat's tumor, cells

from the lung of an aborted human fetus, and others. No luck. There was no sign of cell damage and therefore no evidence of viral growth. Then they tried another line, derived from kidney cells of a fetal rhesus monkey. *Yes* luck. By the middle of March, they could see "cytopathic effect" in their monkey-cell culture, meaning that something had begun to replicate within those cells and destroy them, spilling from one cell to another and creating a visible zone of devastation. Within a few more days, the team had electron microscope images of round viral particles, each particle encircled by a corona of knobs. This was so unexpected that one microscopist on the team had recourse to what amounted to a field guide; he browsed through a book of viral micrographs, looking for a match, as you or I might do for a new bird or a wildflower. He found his match among a group known as the coronaviruses, characterized by a corona of knobby proteins rimming each viral particle.

So the culturing work had established that an unknown coronavirus was present in SARS patients—some of them, anyway—but that didn't necessarily mean it had caused the disease. To establish causality, Peiris's team tested blood serum from SARS patients (because it would contain antibodies) against the newfound virus in culture. This was like splashing holy water at a witch. The antibodies recognized the virus and reacted strongly. Less than a month later, based on that evidence plus other confirming tests, Malik Peiris and his colleagues published a paper cautiously announcing this new coronavirus as "a possible cause" of SARS.

They were right, and the virus became known as SARS coronavirus, inelegantly abbreviated as SARS-CoV. It was the first coronavirus ever found to inflict serious illness upon humans. (Several other coronaviruses are among the many viral strains responsible for common colds. Still others cause hepatitis in mice, gastroenteritis in pigs, and respiratory infection in turkeys.) SARS-CoV has no ominous ring. In older days, the new agent would have received a more vivid, geographical moniker such as Foshan virus or Guangzhou virus, and people would have run around saying: *Watch out, he's got Guangzhou!* But by 2003 everyone recognized that such labeling would be invidious, unwelcome, and bad for tourism.

Several other teams, working independently to isolate a SARS causal agent, had gotten the same answer at about the same time. In the United States, it was a group based at the CDC in Atlanta, with a long list of international partners. In Europe, it was a set of collaborators spread among research institutions in Germany, France, and the Netherlands. In China, it was a small squad of earnest, adept, and deferential researchers who had isolated a coronavirus and photographed it weeks before Peiris's group did the same. These unfortunate Chinese scientists, based at the Academy of Military Medical Sciences, let themselves be cowed by the chlamydia theory and its august promoter in Beijing, passing up their opportunity to announce the real discovery first. "We were too cautious," one of them said later. "We waited too long."

The next logical step for Malik Peiris and his gang, after having identified the virus, sequenced a portion of its genome, and placed it within a family tree of other coronaviruses, was to wonder about its origin. The thing hadn't come out of nowhere. But what was its usual habitat, its life history, its natural host? One scientist involved in the work, a young biologist named Leo Poon, touched on that during a conversation with me in Hong Kong.

"The data that we found in human samples," said Poon, "suggested that this virus is novel to humans. What I mean is that humans had not been infected by this virus before. So it must have been coming from some kinds of animals."

But which animals, and how did they happen to transmit the infection to people? Those questions could only be answered by going into the forests, the streets, the markets, the restaurants of southern China to gather evidence. Nudging him toward that subject, I wondered: "Were you part of the fieldwork?"

"No, I'm a *molecular* scientist," he said. It had been like asking Jackson Pollock if he painted houses, I suppose, but Leo Poon didn't take my question amiss. He was happy to give credit where due. No, another of their colleagues, a wildcat fellow named Guan Yi, with the instincts of an epidemiologist and the balls of a brass macaque, had crossed into China and, with cooperation from some local officials, taken swabs from the throats, the anuses, and the

cloacae of animals on sale in the biggest live market in Shenzhen. Those samples were what first led Leo Poon (who did the molecular analysis), Malik Peiris, Guan Yi himself—and, eventually, scientists and health officials all over the world—to cast their suspicious attentions upon a mammal called the civet cat.

36

In a crowded country with 1.3 billion hungry citizens, it should be no surprise that people eat snake. It should be no surprise that there are Cantonese recipes for dog. Stir-fried cat, in such a context, seems sadly inevitable rather than shocking. But the civet cat (*Paguma larvata*) is not really a cat. More accurately known as the masked palm civet, it's a member of the viverrid family, which includes the mongooses. The culinary trade in such unusual wild animals, especially within the Pearl River Delta, has less to do with limited resources, dire necessity, and ancient traditions than with booming commerce and relatively recent fashions in conspicuous consumption. Close observers of Chinese culture call it the Era of Wild Flavor.

One of those observers is Karl Taro Greenfeld, who served as editor of *Time Asia* in Hong Kong during 2003, oversaw the magazine's coverage of SARS, and soon afterward wrote a book about it, *China Syndrome*. Before his editing role, Greenfeld had covered "the new Asia" as a journalist for some years, giving him opportunity to see what people were putting in their stomachs. According to him:

> Southern Chinese have always noshed more widely through the animal kingdom than virtually any other peoples on earth. During the Era of Wild Flavor, the range, scope, and amount of wild animal cuisine consumed would increase to include virtually every species on land, sea, or air.

Wild Flavor (*yewei* in Mandarin) was considered a way of gaining "face," prosperity, and good luck. Eating wild, Greenfeld explained, was only one aspect of these new ostentations in upscale consumption, which might also involve patronizing a brothel where a thousand women stood on offer behind a glass wall. But the food vogue arose easily from earlier traditions in fancy cuisine, natural pharmaceuticals, and exotic aphrodisiacs (such as tiger penis), and went beyond them. One official told Greenfeld that two thousand Wild Flavor restaurants were now operating within the city of Guangzhou alone. Four more received licenses during the hour Greenfeld spent in the man's office.

These eateries drew their supplies from the "wet markets" of Guangdong province, vast bazaars filled with row after row of stalls purveying live animals for food, such as the Chatou Wildlife Market in Guangzhou and the Dongmen Market in Shenzhen. Chatou began operating in 1998 and within five years had become one of the largest wild-animal markets in China, especially for mammals, birds, frogs, turtles, and snakes. Between late 2000 and early 2003, a team of researchers based in Hong Kong conducted an ongoing survey of wild animals on sale at Chatou, Dongmen, and two other big Guangdong markets. Compared to an earlier survey done in 1993–1994, the team found some changes and new trends.

First, the sheer volume of the wild-animal trade seemed to have increased. Second, there was more cross-border commerce, legal or covert, drawing wildlife from other Southeast Asian countries into southern China. Meaty but precious individuals of endangered species, such as the Bornean river turtle and the Burmese star tortoise, were turning up. Third, greater numbers of captive-bred animals had become available from commercial breeders. Certain kinds of frogs and turtles were being farmed. Snakes, according to rumor, were being farmed. Small-scale civet farms, operating in central Guangdong and southern Jiangxi (an adjacent province), helped supply the demand for that animal. In fact, much of the trade in three popular wild mammals—the Chinese ferret badger and the hog badger in addition to the masked palm civet—seemed to come from farm breeding and rearing. Evidence for this sup-

position, made by the survey team, was that the animals appeared relatively well fed, uninjured, and tame. Caught from the wild, they would more likely show trap wounds and other signs of desperation and abuse.

But even if they arrived healthy and robust from the farm, conditions in the markets weren't salubrious. "The animals are packed in tiny spaces and often in close contact with other wild and/or domesticated animals such as dogs and cats," the survey team wrote. "Many are either sick or with open wounds and without basic care. Animals are often slaughtered inside the markets in several stalls specialising in this." Open wire cages, stacked vertically, allowed wastes from one animal to rain down onto another. It was zoological bedlam. "The markets also provide a conducive environment," the team noted, almost passingly, "for animal diseases to jump hosts and spread to humans."

Guan Yi, the intrepid microbiologist from Hong Kong University, waded into these conditions at Dongmen Market, in Shenzhen, and persuaded sellers to let him take swab samples and blood from some of their animals. Exactly how he persuaded them is still mystifying—force of personality? eloquent arguments? clear explication of scientific urgency?—although holding a thick wad of Hong Kong dollars in his hand apparently helped. He anaesthetized twenty-five animals one by one, swabbed for mucus, swabbed for feces, drew blood, and then took the samples back to Hong Kong for analysis. The hog badgers were clean. The Chinese hares were clean. The Eurasian beavers were clean. The domestic cats were clean. Guan had also sampled six masked palm civets, which weren't clean; all six carried signs of a coronavirus resembling SARS-CoV. In addition, the fecal sample from one raccoon dog (a kind of wild canid, which looks like an overfed fox with raccoon markings), tested positive for the virus. But the data overall pointed most damningly at the civet.

This discovery, the first concrete indication that SARS is a zoonotic disease, was announced at a Hong Kong University press conference on May 23, 2003. One day later, the *South China Morning Post*, Hong Kong's leading English-language newspaper,

ran a front-page story (amid all its other SARS coverage) on the announcement, headlined: SCIENTISTS LINK CIVET CATS TO SARS OUTBREAK. Residents of the city were quite aware, by then, that the SARS contagion traveled on human respiratory emissions from person to person, not just in the juices and flesh of wild meat. Earlier editions of the *Morning Post*, as well as other Hong Kong newspapers, had carried articles accompanied by vivid photos of people in surgical masks—a masked couple kissing, a hospital official demonstrating a mask and visor, a comely model at an auto show wearing a mask decorated with car advertising—as well as hospital staff and soldiers doing infection control in full hazmat suits. Hong Kong's governmental supplies department distributed 7.4 million masks to schools, medical personnel, and health officials on the front line of response, and demand was high too among the general public. Circle K, the convenience store chain, had sold almost a million masks; Sa Sa Cosmetics had moved 1.5 million. Prices per mask had quadrupled. Despite the widespread alarm over person-to-person transmission, though, there was still great interest in learning where this virus had its zoological source.

Using a press conference to break the news about civets, rather than publishing first in a scientific journal, was unorthodox but not unprecedented. Journal publication would have taken longer, because of editorial work, peer review, backlogs of articles, and lead times. Circumventing that process reflected haste, driven by civic concern and the urgency of the outbreak but also possibly by scientific competition. The CDC in Atlanta had shown its own haste just two months earlier in announcing, also by way of a press conference, that scientists there had identified a new coronavirus as the likely cause of SARS. The CDC announcement didn't mention that Malik Peiris and his team had found the same virus and confirmed its connection with SARS three days before. That act of claiming priority by the CDC, unnoticeable to the world at large, probably put the Hong Kong University scientists on edge against their competitors in Atlanta and elsewhere, and contributed to the decision to trumpet Guan Yi's discovery at the earliest reasonable chance.

One immediate consequence of Guan's findings was that the

Chinese government banned the sale of civets. In its uncertainty, the government also banned fifty-three other Wild Flavor animals from the markets. The ban inevitably caused economic losses, generating such foofaraw from animal farmers and traders that in late July, after an official review of the risks, it was rescinded. The rationale for reversal was that another group of researchers had screened masked palm civets and found no evidence whatsoever of a SARS-like virus. Under the revised policy, farm-raised civets could be legally traded again but the sale of wild-caught animals was prohibited.

Guan Yi showed some annoyance at the doubts about his findings. But he forged ahead through scientific channels, presenting a detailed explication and supporting data (tables, figures, genome sequences) in a paper published in *Science* the following October. Leo Poon and Malik Peiris, his HKU colleagues, were included in the long list of coauthors. Guan and company worded their conclusions judiciously, noting that infection of civets didn't necessarily mean that civets were the reservoir host of the virus. The civets might have become infected "from another, as yet unknown, animal source, which is in fact the true reservoir in nature." They might have functioned as amplifier hosts (like those Hendra-infected horses in Australia). The real point, according to Guan and his colleagues, was that the wet markets such as Dongmen and Chatou provided a venue for SARS-like coronaviruses "to amplify and to be transmitted to new hosts, including humans, and this is critically important from the point of view of public health."

By the time that paper appeared, the SARS epidemic of 2003 had been stopped, with the final toll at 8,098 people infected, of whom 774 died. The last case was detected and isolated in Taiwan on June 15. Hong Kong had been declared "SARS-free." Singapore and Canada had been declared "SARS-free." The whole world was supposedly "SARS-free." What those declarations meant, more precisely, was that no SARS infections were currently raging in humans. But the virus hadn't been eradicated. This was a zoonosis, and no disease scientist could doubt that its causal agent still lurked within one or more reservoir hosts—the palm civet, the rac-

coon dog, or whatever—in Guangdong and maybe elsewhere too. People celebrated the end of the outbreak, but those best informed celebrated most guardedly. SARS-CoV wasn't gone, it was only hiding. It could return.

In late December, it did. Like an aftershock to a quake, a new case broke in Guangdong. Soon afterward, three more. One patient was a waitress who had been exposed to a civet. On January 5, 2004, the day the first case was confirmed, Guangdong authorities reversed policy again, ordering the death and disposal of every masked palm civet held at a farm or a market in the province. Wild civets were another question, left unanswered.

Eradication teams from the Forestry Department (which regulates the wild animal trade) and the Health Department went out to civet farms. During the days that followed, more than a thousand captive civets were suffocated, burned, boiled, electrocuted, and drowned. It was like a medieval pogrom against satanic cats. This campaign of extermination seemed to settle the matter and made people more comfortable. That sense of comfort remained for, oh, a year or more—until other scientists showed that the doubts about reservoir identification were well-founded, that the judicious language of Guan Yi was percipient, and that the story was just a little deeper and more complicated. Woops, civets aren't the reservoir of SARS. Never mind.

37

It was Leo Poon who told me about the wild civets of Hong Kong. We were sitting in a small meeting room by the elevator on an upper floor of the Medical Faculty building at Hong Kong University, on its hillside above the towering banks and other sleek skyscrapers rising like spikes of obsidian above Central district. Below and beyond, across Victoria Harbor, were the funky streets,

market stalls, alleys, shops, noodle parlors, housing projects, and tourist destinations of Kowloon, including the Metropole Hotel, now sterilized and renamed, where I was staying. I hadn't imagined there was much of *anything* wild in such a hectic environment of people and vehicles and vertical concrete, but only because I'd been limited to a cityside view of Hong Kong. Wild civets, *oh yes*, out in the New Territories, Poon assured me. Those so-called New Territories (new to the colonial British when they leased them from China in 1898 for ninety-nine years) still encompass the less developed areas of the Hong Kong Special Administrative Region, from Boundary Street on the north edge of Kowloon to the Guangdong border, plus outlying islands, with forests and mountains and nature reserves that show green on a map. These are places where, even into the twenty-first century, masked palm civets might survive in the wild. "They're all over the countryside!" Poon said.

Just after the epidemic ended, his HKU team started trapping animals out there to look for evidence of coronavirus. They focused first on civets, capturing and sampling almost two dozen. From each animal they took a respiratory swab and a fecal swab—zip zap, thank you very much—and then released the civet back to the Hong Kong wilds. Each sample was screened by PCR methodology using what the technical lingo calls "consensus primers," meaning generalized molecular jump-starters that would amplify RNA fragments shared commonly among coronaviruses, not just those unique to the SARS-like coronavirus that Guan Yi had found in his civets. So how much coronavirus did Poon find? I asked. "None at all," he said. That absence suggested that the civet is not the reservoir for SARS coronavirus. "We were quite disappointed."

But disappointment, in science, is sometimes a gateway to insight. If not the civet, then what? "We hypothesized that, if this animal"—this unidentified creature—"is the natural reservoir for SARS, it must be quite widespread." So they trapped, in several sylvan locations, whatever wild and feral animals they could find. The eventual list was richly various, ranging from rhesus macaques to porcupines, from rat snakes to turtle doves, from wild boars to black rats, and including at least one Chinese cobra. Again the

PCR results were almost universally negative—almost. Only three kinds of animal out of forty-four showed any sign of infection with a coronavirus. All three were microchiropterans. To you and me: little bats.

Only one of those registered high prevalence as a group, with most of the sampled individuals testing positive, as measured by virus shed in their feces: a delicate thing called the small bent-winged bat.

Poon gave me a copy of the paper he published (sharing credit, again, with Guan and Peiris among its coauthors) in the *Journal of Virology* in 2005, about a year after the great civet slaughter. He wanted me to be clear about his findings. "This bat coronavirus is quite different from SARS," Poon said. That is, he didn't claim to have found the reservoir of SARS-CoV. "But this *is* the first coronavirus in a bat." That is, he had turned up a strong clue.

Soon afterward, an international team of Chinese, American, and Australian researchers published an even more revealing study, based on sample collections they made in Guangdong and three other Chinese sites. This team, led by a Chinese virologist named Wendong Li, also included Hume Field, the laconic Australian who had found the reservoir of Hendra, and two scientists from the Consortium for Conservation Medicine, based in New York. Unlike the Hong Kong sampling study, Li's focused specifically on bats. The team trapped animals from the wild, drew blood, took fecal and throat swabs, and then analyzed duplicate samples of the material independently at labs in China and Australia, creating a double-check on themselves that strengthened the certitude of their results. What they found was a coronavirus that, unlike Leo Poon's, closely resembled SARS-CoV as seen in human patients. They called it SARS-like coronavirus. Their sampling showed that this SARS-like virus was especially prevalent in several bats belonging to the genus *Rhinolophus*, known commonly as horseshoe bats. Horseshoe bats are delicate little creatures with large ears and flanged, opened-out noses that, homely but practical, seem to play a role in directing their ultrasonic squeaks. They roost mainly in caves, of which southern China has an abundance; they emerge

at night to feed on moths and other insects. The genus is diverse, encompassing about seventy species. Li's study showed bats of three species in particular carrying SARS-like virus: the big-eared horseshoe bat, the least horseshoe bat, and Pearson's horseshoe bat. If you ever notice these animals on the menu of a restaurant in southern China, you might want to choose the noodles instead.

High prevalence of antibodies to the virus among horseshoe bats, compared with zero prevalence among wild civets, was an important discovery. But there was more. Li's team also sequenced fragments of viral genome extracted from fecal samples. Comparative analysis of those fragments showed that the SARS-like virus contained, from sample to sample, considerable genetic diversity—more diversity than among all the isolates of SARS-CoV as known from humans. This virus seemed to have been in the bat populations for some time, mutating, changing, diverging. In fact, the totality of diversity known in the human SARS virus nested *within* the diversity of the bat virus. That sort of nesting relationship can best be depicted as a family tree. Li and company drew one. It appeared as a figure in the paper they published in *Science.* Human SARS virus was a single branch, skinny and small, within a limb of branches representing what lives within horseshoe bats.

What did this mean? It meant that horseshoe bats are a reservoir, if not *the* reservoir, of SARS-CoV. It meant that civets must have been an amplifier host, not a reservoir host, during the 2003 outbreak. It meant that no one knew just what had happened in Guangdong that winter to trigger the outbreak, although Li and his colleagues could speculate. ("An infectious consignment of bats serendipitously juxtaposed with a susceptible amplifying species," they wrote, "could result in spillover and establishment of a market cycle while susceptible animals are available to maintain infection." Infection by association. Susceptible animals might include not just masked palm civets but also raccoon dogs, ferret badgers, who knows what. So many different candidates pass through the wildlife supply chain.) It meant that you could kill every civet in China and SARS would still be among you. It meant that this virus existed—facing its ecological limits and opportunities—within a

culture where "an infectious consignment of bats" might arrive at a meat market as a matter of course. It meant, Let the diner beware. And it meant that further research was needed.

38

Aleksei Chmura is a young American researcher of mild demeanor, clean-cut appearance, diverse experience, and catholic tastes. He grew up in Connecticut, quit college, traveled, worked as a baker, trained as a chef, shifted to furniture restoration, and reentered academia after ten years to study environmental science. Employed, when I first encountered him, in an administrative capacity by the Consortium for Conservation Medicine (a program of Wildlife Trust, which has since been renamed EcoHealth Alliance), he was also gathering data toward a doctorate on the ecology of zoonotic diseases in South Asia, particularly SARS. For that he was collecting samples from bats. He invited me to come out and see some of the work. On the agreed date he met my flight in Guangzhou, and I suppose the durian should have been my first signal that he was a temerarious eater.

Just in from the airport, Chmura and I joined a group of his friends at Sun Yat-sen University and plunged into a snack of the world's stinkiest fruit. It's a large spiky thing, a durian, like a puffer fish that has swallowed a football; pried open, it yields individual gobbets of glutinous creamy pulp, maybe eight or ten gobbets per fruit, and an unwelcoming bouquet. The pulp tastes like vanilla custard and smells like the underwear of someone you don't want to know. We ate barehanded, slurping the goo between our fingers as it oozed and dripped. This was before dinner, in lieu of peanuts and beer. Then we went out to a restaurant where Chmura ordered us a dish featuring congealed pig's blood—in little hepatic cubes, like diced liver—with bean sprouts and hot red peppers. By late

evening my shirt was soaked with sweat. Welcome to China. But I was keen to learn what Aleksei Chmura knew, to benefit from his voracious curiosity, and I would eat my way toward insight at his side, if necessary.

Next day we flew onward to the city of Guilin, northwest of Guangzhou, in a river valley famed for its karst-mountain vistas and its caves. The mountains rose abruptly, like croquettes on a plate, but they were forested in green and riddled with natural cavities, chutes, potholes, and nooks weathered out through the soluble limestone of the karst. It was a good place to be a tourist, if you wanted dramatic scenery, and a good place to be a bat, if you wanted to roost. We hadn't come for the scenery.

But before the bat work began, Aleksei took me out to a food market for a glimpse of what's presently available in Guilin's aboveground economy. Strolling the narrow corridors between stalls, I saw vegetables laid out in neat bundles. The fruits were carefully piled. The mushrooms were gnomic. The red meat was sold mainly in slabs, joints, and pieces by women at large plywood tables, wielding sharp cleavers. The catfish, the crabs, and the eels churned slowly in aerated tanks. The bullfrogs huddled darkly in scrums. It was grim to be reminded how we doom animals with our appetite for flesh, but this place seemed no more odd or morbid than a meat market anywhere. That was the point. This was the "after" condition in a "before/after" contrast revealing how SARS had put a damper on yewei. What had changed here in recent years, Aleksei told me, was the disappearance of the trade in wildlife. Things had been far different in 2003—and even in 2006, when he first started visiting wet markets in southern China.

At the Chatou market in Guangzhou, for instance, he had seen storks, seagulls, herons, cranes, deer, alligators, crocodiles, wild pigs, raccoon dogs, flying squirrels, many snakes and turtles, many frogs, as well as domestic dogs and cats, all on sale as food. There were no civets, not when he saw the place; they had already been demonized and purged. The list he recited was just a selection, from memory and from his own discreet inspections, of what food markets were offering then. You could also buy leopard cat, Chi-

nese muntjac, Siberian weasel, Eurasian badger, Chinese bamboo rat, butterfly lizard, and Chinese toad, plus a long list of other reptiles, amphibians, and mammals, including two kinds of fruit bat. Quite an epicure's menu. And of course birds: cattle egrets, spoonbills, cormorants, magpies, a vast selection of ducks and geese and pheasants and doves, plovers, crakes, rails, moorhens, coots, sandpipers, jays, several flavors of crow. One fellow, a Chinese colleague of Aleksei's, told me that the bird-and-bat trade was covered by an adage: "People in south China will eat everything that flies in the sky, except an airplane." He was a northerner himself.

After the SARS outbreak and the civet publicity, local governments (presumably with some pressure from Beijing) had tightened down, enacting new restrictions against wildlife in the markets. The Era of Wild Flavor hadn't ended but it had been driven underground. "There's still a lot of people in China that believe eating fresh, wild animals is good for your respiratory system, it's good for sexual potency, whatever," Aleksei said. But tracing the traffic now, let alone measuring it, was difficult. Market sellers had gotten wary, and especially wary of obvious outsiders such as Aleksei, a westerner speaking hesitant Mandarin, who might come snooping around. Wild animals were still available, no doubt, but they would be under the counter, or going out the back door, or traded from a van that stopped on a certain street corner at 2 a.m. If you wanted to feast on a Burmese star tortoise or a muntjac nowadays, you would need to know somebody who knew somebody, pay premium rates, and make your arrangements beyond the sight of the crowds.

Aleksei himself, I discovered as we shared time and meals, harbored a robustly unusual attitude on the subject of carnivorism—unusual, anyway, for an American. He didn't judge yewei harshly. He didn't disapprove of eating an animal, virtually any animal, so long as it hadn't been illegally harvested, it didn't belong to a threatened species, and it wasn't contaminated with the sort of pernicious microbes he'd come to study. One evening as we sat together over a pot of delicate little fish and bamboo shoots, crunching the fish heads and backbones as we chewed, I tried to push him to articulate his scruples. I suppose my questions were obvious and sim-

plistic. What animals *won't* you eat, Aleksei? Tell me what kinds are off limits. Primates? Would you dine on a monkey? Without a blink he said yes, with a proviso: that the monkey meat seemed appetizing. What about ape? If you were in Africa, would you eat gorilla or chimpanzee? "I can't draw the line there," he answered. "It's either eat meat, or don't eat meat. You'd have to test me by putting human flesh in front of me." This could have sounded ghoulish, provocative, or just silly, but it didn't, because he was earnestly trying to answer my hypothetical with candor and logic. Taxonomy simply wasn't among his guiding standards of diet. Back in New York, he had told me, he lives mainly on fruit.

We spent the following days, in and around Guilin, trapping bats. The karst mountains, with all their erosional hollows, offered plenty of roosting sites. The trick was to find which caves were presently in use. For scouting the good spots, and for help with the netting and processing, Aleksei was assisted by several Chinese students, including a young ecologist named Guangjian Zhu, from East China Normal University in Shanghai. With years of experience, Guangjian was an expert handler of bats, sure-fingered and steady with the delicate little animals as they tried to wriggle free from a mist net, bite him, and escape. He was small, lean, and strong, an agile climber, an unhesitating spelunker, traits that serve well for studying bats in the wild. Yang Jian, another student, knew the local terrain and led the way to the caves. Late on the third afternoon, we four took a taxi to the outskirts of Guilin and, armed with our nets and poles, began walking down a narrow village lane. Late afternoon is when a person goes trapping for cave-roosting bats, so that they can be caught as they emerge for a night's feeding.

Just outside the village, with the sun sinking blearily behind Guilin's smog, we tromped through a citrus grove, then a pea field, then a zone of high weeds, and ascended on a faint tunnel-like trail through the hillside vegetation, a thicket of thorns and vines and bamboo. After a brief traverse, we came to a hole in the slope, not much larger than an old cellar door. Guangjian and Jian climbed down into it and disappeared; Aleksei and I followed. Beyond the hole was a small foyer and, on the far side of that, a low slot, like a

mountain's smirk, leading onward. We belly crawled through and came up dirty in a second small chamber. Not for the claustrophobic. We crossed that chamber and then butt skidded through another low gap, down another rabbit hole into a third chamber (this all felt a little like being swallowed through the multiple stomachs of a cow), which opened out wider and deeper. Here we found ourselves perched high above the floor, as though on the sill of a second-floor window. We could feel the flutter of little bats whirling through the air around our faces. Which of them carries this deadly virus? I wondered.

Bats everywhere, that was good—but would we, from our perch in a high corner, be able to catch any? I couldn't see how. Then again, I couldn't see much of anything. By the light of my headlamp, I found myself a small ledge of knobby limestone on the sloping wall of the room, settled my rear upon it, and waited for whatever would happen next. What happened, to my surprise, was that Aleksei and Guangjian spread a mist net across the hole we had just come through, sealing us inside the chamber. Now the bats were sealed in too. The air was cozily warm. Mmm, yum. The net immediately began stopping little creatures, scarcely audible as they hit and stuck, like flies in a spider's web. Exit blocked, they couldn't escape us. We were the spider.

Aleksei and Guangjian untangled the bats quickly, dropping each into a cloth bag and handing the bags to me. My assigned job was to hang the bags, like laundry, on a horizontal pole I had rigged into place between rocks. It seems that bats remain more calm and comfortable—even bats in cloth bags—when they dangle. Jian meanwhile stood at the bottom of the chamber, sweeping the air with a butterfly net to catch other bats in flight, and cursing at them mildly in English when he missed.

At this moment I became conscious of a dreary human concern: Though we were searching for SARS-like coronavirus in these animals, and sharing their air in a closely confined space, none of us was wearing a mask. Not even a surgical mask, let alone an N95. Um, why *is* that? I asked Aleksei. "I guess it's like not wearing a seat belt," he said. What he meant was that our exposure represented a calculated, acceptable risk. You fly to a strange country,

you jump into a cab at the airport, you're in a hurry, you don't speak the language—and usually there's no seat belt, right? Do you jump out and look for another cab? No, you proceed. You've got things to do. You might be killed on the way into town, true, but probably you won't. Accepting that increment of risk is part of functioning within exigent circumstances. Likewise in a Chinese bat cave. If you were absolutely concerned to shield yourself against the virus, you'd need not just a mask but a full Tyvek coverall, and gloves, and goggles—or maybe even a bubble hood and visor, your whole suit positive-pressurized with filtered air drawn in by a battery-powered fan. "That's not very practical," Aleksei said.

Oh, I said, and continued handling the bagged bats. I couldn't disagree. But what I thought was, Catching SARS—*that's* practical?

Back at the laboratory in Guilin, Aleksei divided the processing chores into a sort of assembly line, with Guangjian as chief handler, Jian assisting, Aleksei himself intervening at delicate moments; all three of them had pulled on blue latex gloves. Guangjian coaxed each bat out of its bag, gripping it gently but firmly. He weighed it, measured it, and identified it by species, while Jian recorded those data. *Rhinolophus pusillus,* least horseshoe bat. *Rhinolophus affinis,* intermediate horseshoe bat. *Hipposideros larvatus,* intermediate roundleaf bat. From each animal, Guangjian took mouth-swab and anal-swab samples, handing the swabs to Jian, who broke off the cotton tips and let them drop into tubes for preservation. Then Aleksei leaned in with a needlelike tool to puncture a certain small vein near the bat's tail—just a light prick, yielding one or two drops of blood. You can't take five milliliters by syringe from such a small animal, he had explained, as you might from a monkey or a civet; you'd suck the poor bat dry. Two drops were enough for two samples, duplicates, each of which could be screened independently for virus. Jian drew the blood away with a delicate pipette, drop by drop, and released it into a tube of buffer. One complete set of blood samples and swabs would go to Shanghai, the other to New York.

The three men worked smoothly together, all tasks assigned and routinized. The routine reduced risk of jabbing one another, stressing a bat unnecessarily by clumsiness or delay, or losing data. After

processing, the bats were released alive from the third-floor laboratory window—most of them, anyway. There were some unintended fatalities, as there often are in any capture and handling of wild animals. Tonight, among twenty bats caught, two died. One was a least horseshoe bat, tiny as a shrew, killed instantly in the cave by a blow from the rim of Jian's butterfly net. If he couldn't release it, Aleksei decided, he should at least dissect the dead bat, salvaging what data he could.

I watched over his shoulder as he worked with a small scissors, puncturing the skin and then zipping upward across the little bat's chest. He spread the pelt back with his fingers—a light pull was enough—to reveal huge breast muscles, reddish purple as sirloin. This animal was built like Mighty Mouse. Aleksei cut through those flight muscles and then through the bones beneath, too delicate to give much resistance to his scissors. With a pointy aliquot, he drew some blood directly from the heart. He snipped out the liver and spleen, dropping them into separate tubes. And for these tasks, I noticed, the seatbelt analogy didn't apply; in addition to his blue gloves, Aleksei donned an N95 mask. Still, it was very undramatic. Only later did I notice the connection between least horseshoe bats and what Wendong Li's group had discovered. The least horseshoe bat is one of the suspected reservoir hosts of the virus.

Once finished, with the blood and organs preserved, Aleksei dropped the carcass into a Ziploc bag. He added the other bat carcass, after dissection, to the same bag. Where do those go? I asked. He pointed to a biohazardous waste box, specially designed for accepting suspect materials.

"But if they were food," he added, "they'd go there," indicating an ordinary trash basket against the wall. It was a shrug back toward our dinner discussions and the tangled matter of categorical lines: edible animals versus sacrosanct animals, safe animals versus infected animals, dangerous offal versus garbage. His point again was that such lines of division, especially in southern China, are arbitrarily and imperfectly drawn.

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Several days later we traveled down to the city of Lipu, about seventy miles south of Guilin, to visit a rat farm that interested Aleksei. The trip took two hours on a rather luxurious bus—one offering seat belts and bottled water. At the bus station in Lipu, while waiting for our local contact to arrive, I noticed a sign stipulating security restrictions. The sign was in traditional Chinese characters but I could tell from the illustrations what was disallowed on board Lipu–Guilin busses: no bombs, no fireworks, no gasoline, no alcohol, no knives, and no snakes. We weren't carrying any.

Mr. Wei Shangzheng eventually pulled up in a white van. He was a short, stocky, amiable man who laughed easily and often, especially after his own statements, not because he thought he was funny but from sheer joy at life's curious sweetness. That's the impression I took, anyway, as his words came translated by Guangjian and his attitude shone merrily through. We climbed into his van and rode six miles to a village northeast of Lipu, where Mr. Wei turned onto a narrow lane, then through a gate, above which was a line of calligraphy announcing: SMALL HOUSE IN THE FIELD BAMBOO RAT RAISING FARM. Beyond was a courtyard surrounded on three sides by cinderblock buildings. Two wings of the building were filled with low concrete pens. The pens contained silver-gray creatures, small-eyed and blunt-headed, that looked like gigantic guinea pigs: Chinese bamboo rats. Mr. Wei gave us a tour up and down the rows.

The pens were clean and well-drained, each furnished with a water dish and holding one to four animals. The Chinese bamboo rat is native to southern China and thereabouts, and the chewed-upon stalks of bamboo in some cages signaled that its diet is true to its name. The front teeth are beaverlike, well suited for gnawing those stalks, but in disposition a bamboo rat is more comparable to a pussycat. Mr. Wei lifted one by the scruff of its neck, turned it over, and gently poked at its sizable scrotum. Don't try that with a beaver. The animal barely wriggled. Up and down the line we could

see adults, juveniles, one female nursing two mouse-size pups, a mounting in progress. They breed readily, Mr. Wei explained. He kept mostly females, plus a few good studs. Last month he sold two hundred rats, and now he was expanding his operation, building new sheds. Already he was the largest bamboo-rat farmer in southern China! he told us exuberantly. Southern China, yes, and maybe beyond! After the expansions, with capacity for five thousand animals, he might be the largest bamboo-rat farmer in all China! He stated this not to brag, it seemed, but in joyous amazement at the vagaries of fortune. Business was good. Life was good. He laughed—ha ha ha!—at the thought of life's goodness. He's famous! he told us. He had been featured on Chinese TV! We could Google him! His ventures in bamboo-rat husbandry began in 2001, when he lost his job at a factory and decided to try something new.

Enterprising and innovative, Mr. Wei now also had two pairs of large, rather menacing porcupines, which sulked in larger pens at the end of one room. He was diversifying. He had begun to breed them and, yes, their offspring too would be sold as food. A special product for special occasions, targeting the wealthier, more jaded epicure. A pair of porcupines was worth $1,000, Mr. Wei said. He did not lift one and poke its scrotum.

I noticed several hypodermic syringes lying ready along the edge of a pen. Was he concerned about the health of his bamboo rats? I asked. Yes, very, said Mr. Wei, especially regarding viruses. They're invisible. They're dangerous. And you can't run a bamboo-rat farm if the animals are sick. He showed us how he would inject an ailing rat on the inside of its calf. He didn't mention what sort of medicine he injected, and most likely it was an antibiotic (therefore useless against viruses), not a newly developed SARS vaccine already available at the level of bamboo-rat wholesaling. But at least Mr. Wei's animals might be free of common bacterial infections at time of sale. What they encountered thereafter—confined to their cages among tenements of other creatures, coughed upon, peed upon, shat upon by bats or civets or raccoon dogs in a warehouse or a wet market—that was a different matter.

After the tour, Mr. Wei insisted we stay for dinner. He had commanded his family to prepare a small banquet. We sat at a low table on tiny chairs with an electric burner amid us, atop which Mr. Wei's elderly mother assembled a formidable hotpot. Into the boiling broth she slid portions of chopped pork, chopped duck, some sort of potatolike tuber, enoki mushrooms, bean sprouts, bok choy, and greens from a plant related to morning glory. She stirred. She added dabs of salt. The ingredients cooked quickly, floated up, and combined to a savory stew, which we picked at with chopsticks and ladled into our rice bowls. Separately, on a cool platter, she offered us roasted gobbets of bamboo rat.

The rat meat was mild, subtle, faintly sweet. There were many small femurs and ribs. One eats bamboo-rat hocks with one's fingers, I learned, sucking clean the bones and piling them politely on the table beside one's bowl, or else dropping them on the floor (the preferred method of Mr. Wei's father, a shirtless old man seated to my left), where they would be scavenged by the skinny cat who slept under the table. The hotpot was scorching. Mr. Wei, an exemplary host, brought out some big bottles of Liquan beer, Guilin's finest brew, nicely chilled. After a few glasses, I got into the spirit of the meal and found myself turning back to the rat platter, browsing for choice morsels.

I had begun to see Aleksei's point: If you're a carnivore, you're a carnivore, so what's the merit of fine distinctions? And if you're going to eat bamboo rat, I figured, best to do it here, at the source—before the poor animals get shipped, stacked amid other animals, and sick. Wild Flavor doesn't need to be seasoned with virus.

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Apart from the aftershock cases in early 2004, SARS hasn't recurred . . . so far. The known events of the 2003 outbreak are still being interpreted. Many bits aren't known. Many questions remain unanswered. Are bats the sole reservoir hosts of SARS-like coronavirus? If so, which kinds of bats? Is the coronavirus that was detected in least horseshoe bats the direct ancestor of SARS-CoV as found in humans? If so, how did the original spillover occur? Was it just a single transmission—from one bat into one civet—or several such happenings? And from civet into human—how many occurrences, how many independent spillovers? Did a cage full of infected civets, sold one by one in a market, send the disease off in multiple directions at once? What exactly happened on the ninth floor of the Metropole Hotel? Did Professor Liu vomit in the corridor, or did he merely sneeze, merely cough—merely exhale? How did the virus evolve during its passage through 8,098 humans? What role did the unique culinary culture of southern China play in bringing a dangerous pathogen out to Hong Kong and then to the world? Where do Mr. Wei's bamboo rats go after leaving the Small House in the Field Bamboo Rat Raising Farm? How are they handled, amid what other animals, what piles of cages, what flying excretions, before reaching the restaurants of Guilin, Guangzhou, and Shenzhen? Why are some people superspreaders, when infected with this virus, but not others? What is the numerical value of R_0 for SARS? When will the virus emerge again? Aleksei Chmura is just one researcher among many trying to add new data to the dossier in which these questions reside.

Much has been written about SARS in the scientific literature since spring of 2003. Most of those papers are narrowly technical, addressing the details of molecular evolution, reservoir relationships, or epidemiology, but some take a broader view, asking *What is it that makes this virus unusual?* and *What have we learned from the SARS experience?* One thought that turns up in the latter sort is that "humankind has had a lucky escape." The scenario could

have been very much worse. SARS in 2003 was an outbreak, not a global pandemic. Eight thousand cases are relatively few, for such an explosive infection; 774 people died, not 7 million. Several factors contributed to limiting the scope and the impact of the outbreak, of which humanity's good luck was only one. Another was the speed and excellence of the laboratory diagnostics—finding the virus and identifying it—performed by Malik Peiris, Guan Yi, their partners in Hong Kong, and their colleagues and competitors in the United States, China, and Europe. Still another was the brisk efficiency with which cases were isolated, contacts were traced, and quarantine measures were instituted in southern China (after some early confusion and denial), Hong Kong, Singapore, Hanoi, and Toronto; and the rigor of infection-control efforts within hospitals, such as those overseen by Brenda Ang at Tan Tock Seng. If the virus had arrived in a different sort of big city—more loosely governed, full of poor people, lacking first-rate medical institutions—it might have escaped containment and burned through a much larger segment of humanity.

One further factor, possibly the most crucial, was inherent to the way SARS-CoV affects the human body: Symptoms tend to appear in a person before, rather than after, that person becomes highly infectious. The headache, the fever, and the chills—maybe even the cough—precede the major discharge of virus toward other people. Even among some of the superspreaders, in 2003, this seems to have been true. That order of events allowed many SARS cases to be recognized, hospitalized, and placed in isolation before they hit their peak of infectivity. The downside was that hospital staff took the first big blasts of secondary infection; the upside was that those blasts generally weren't emitted by people still feeling healthy enough to ride a bus or a subway to work. This was an enormously consequential factor in the SARS episode—not just lucky but salvational. With influenza and many other diseases the order is reversed, high infectivity preceding symptoms by a matter of days. A perverse pattern: the danger, then the warning. That probably helped account for the scale of worldwide misery and death during the 1918–1919 influenza: high infectivity among

cases before they experienced the most obvious and debilitating stages of illness. The bug traveled ahead of the sense of alarm. And that infamous global pandemic, remember, occurred in the era *before* globalization. Everything nowadays moves around the planet faster, including viruses. If SARS had conformed to the perverse pattern of presymptomatic infectivity, its 2003 emergence wouldn't be a case history in good luck and effective outbreak response. It would be a much darker story.

The much darker story remains to be told, probably not about this virus but about another. When the Next Big One comes, we can guess, it will likely conform to the same perverse pattern, high infectivity preceding notable symptoms. That will help it to move through cities and airports like an angel of death.

Two days after our dinner at the rat farm, I rose early in Guilin, said my farewell to Aleksei Chmura, and caught a plane back to Guangzhou. I killed some hours in the airport there, paying more yuans for a ham sandwich and two lattes than I'd spent on a week's meals in the cafés and noodle parlors of Guilin. Then I boarded my onward flight. In the row beside me were two young Japanese tourists, a couple, possibly returning from a romantic vacation amid the hotels, parks, malls, markets, restaurants, and crowded streets of Guangzhou or other cities of southern China. They took their seats unobtrusively and settled in for the short ride to Hong Kong. Maybe they felt a bit cowed by their own adventurousness and relieved to be headed home to a tidier nation; maybe they remembered the news stories about SARS. I didn't intrude on them with questions. I wouldn't have noticed them at all, except they were both wearing surgical masks.

Yes, I thought, if only it were that simple.

146. *"the number of infections distributed in a community"*: MacDonald (1956), 375.
147. *"It all but destroyed malariology"*: Harrison (1978), 258.
151. *"The effect was remarkable"*: Desowitz (1993), 129.
152. *"This occurrence," wrote a quartet of the doctors involved*: Chin et al. (1965), 865.
161. *"it is possible that we are setting the stage for a switch"*: Cox-Singh and Singh (2008), 408.

IV. Dinner at the Rat Farm

169. *"hospitalized for treatment of severe, acute respiratory syndrome"*: World Health Organization (2006), 257.
169. *"During the past week," it said, "WHO has received reports"*: World Health Organization (2006), 259–60.
171. *described simply as "a local government official"*: Abraham (2007), 30.
171. *labeling it "atypical pneumonia"*: Abraham (2007), 34.
172. *"Population estimates of* R_0 *can obscure"*: Lloyd-Smith et al. (2005), 355.
173. *"Each time they began to insert the tube"*: Abraham (2007), 37.
182. *alarming rumors about "a strange contagious disease"*: World Health Organization (2006), 5.
184. *"The first thing going through our minds"*: Normile (2003), 886.
185. *announcing this new coronavirus as "a possible cause"*: Peiris (2003), 1319.
186. *"We were too cautious," one of them said later*: Enserink (2003), 294.
187. *"Southern Chinese have always noshed more widely"*: Greenfeld (2006), 10.
189. *"The animals are packed in tiny spaces"*: Lee et al. (2004), 12.
191. *"from another, as yet unknown, animal source"*: Guan et al. (2003), 278.
195. *"An infectious consignment of bats"*: Li et al. (2005), 678.
206. *"humankind has had a lucky escape"*: Weiss and McLean (2004), 1139.

V. The Deer, the Parrot, and the Kid Next Door

211. *known initially as "abattoir fever"*: Sexton (1991), 93.
212. *an example of "public hysteria" commensurate with flagellation*: *The Washington Post*, January 26, 1930, 1.
214. *"three died in agony"*: Van Rooyen (1955), 4.