After the first two weeks of decomposition, the blow flies and the flesh flies start to leave the corpse to pupate, and since they do not usually return to the same corpse to produce a second generation, their usefulness as indicators of the minimum period since death decreases. After the departure of these flies, the emphasis in estimating the postmortem interval shifts from the developmental cycles of individuals and species to the succession patterns of all the insects and other arthropods present on and around the corpse during the various stages of decomposition.

As the maggots of the blow flies and flesh flies remove the moist, soft tissues of the body, the corpse begins to dry and to attract such species as the hide beetles, which eat dried skin and cartilage but do not like moist food. Some species that prey on the maggots are not equipped to prey on the better-armored
beetles or their larvae. And so the predators and parasites that exploit flies leave the corpse as the maggots disappear, being replaced by species that are able to feed on the beetles and their larvae. Some species of beetles arrive as adults and lay their eggs; then their developing larvae prey on the maggots. Their rate of development is usually keyed to the rate of development of the maggots and they reach the pupal stage when the maggots depart. The larvae and adults of many insects are equipped to use completely different food sources. Thus the predatory larvae of a species that feeds on maggots may develop into adults that feed only on the dried tissues of the corpse. Unless interrupted, patterns like this continue, although with a succession of different players, until the corpse is reduced to skeletal material and the normal fauna of the area returns. Months or even years may pass before the area around the corpse returns to normal.

To use succession patterns successfully when I am estimating the postmortem interval, I must rely heavily on the data obtained from decomposition studies that I have conducted in various habitats—or for cases outside Hawaii, on decomposition studies done by others. Ideally, of course, I would have such data for the exact spot where the body was discovered. This has happened to me only once; in that case, the corpse was dumped into a ravine just outside of Lyon Arboretum in the Manoa Valley, approximately 25 meters away from where I had been conducting decomposition studies. Almost always, however, the corpse is discovered some distance from the location of any of my decomposition studies and I must find the best match I can with known sites.

Even though estimations of the postmortem interval during the early stages of decomposition are based primarily on the developmental rates of individual species of flies, succession patterns do enter into these estimates because most species of flies lay eggs more than once on a dead body. Typically the corpse is attractive to female flies of some species for several days. After that period, the corpse will have changed and will no longer be an attractive egg-laying place for these species of flies, and other species will take over. But since there have already been several days of egg laying before this switch occurs, there will be several different stages of development of any given species of maggot on the corpse after the first day of insect activity. As decomposition progresses, these different stages will continue in waves, ending only when the maggots from the last clutch of eggs laid complete their development to the pupal stage. The presence or absence of these different stages on a corpse can buttress the estimate derived from the development of a single set of maggots.

Consider the case of a body discovered by a jogger at the edge of Kawaiulii Marsh on Oahu at approximately 5:30 P.M. on August 26, 1985. When the police arrived, they found the body of a male, clad in a T-shirt and pants, lying supine at the edge of the marsh with legs extended and arms at the side. The body was decomposed beyond recognition and heavily infested with maggots. The lower abdomen had been opened by maggot activity and the pants were pulled down to mid-thigh, but still fastened. A hat, with what appeared to be a bullet hole above the visor on the right front, was found near the body; it was later shown that this hat belonged to the victim.

I first saw the corpse during the autopsy at the morgue on the morning of August 27. Upon entering the autopsy room, I immediately noticed a strong odor of ammonia. There was also a greenish discoloration of the skin, which I have since learned to associate with a body that has been immersed in water. The head had been stripped to the skull, although some skin clung to the sides and the ears were largely intact. The upper portions of the chest were skeletonized and contained a large mass of late instar maggots. The groin area was also largely decomposed and contained both early and late instar maggots. Maggots had not yet
invaded the abdominal cavity, which was still intact. There were also maggots on the arms and legs, but they were not forming feeding masses. The cause of death was said to be a gunshot wound to the head, and the medical examiner declared the death a homicide, but no fragments or intact bullets were recovered from the body.

After collecting and treating my specimens I returned to my laboratory with the maggots. Initial examination of the maggots showed that there were at least two species present, each represented by several different stages of development, indicating that adult flies had laid eggs at several different times. I easily identified one of the species as *Chrysomya rufifacies* because this blowfly’s maggots have quite distinctive spine-like projections and stand out from the rest of the maggots found in Hawaii. This species was present in a large mass in the chest cavity and in the groin area, and on the arms and legs. The specimens I collected from the chest cavity and groin were second and third instar maggots; those from the arms and legs were post-feeding third instar larvae, measuring 12 to 15 millimeters in length. These maggots, found as both second and third instars, lacked the distinctive spines of *Chrysomya rufifacies*. The most mature third instar maggots for this species were 14 to 16 millimeters long. Although this species was abundant on the chest and in the groin, I did not find any specimens on either the arms or legs. I placed samples of both the second and third instar maggots on beef liver and reared them to the adult stage in the environmental chamber. I suspected that these would prove to be the other common species of blow flies found during the early stages of decomposition in Hawaii, *Chrysomya megacephala*. When the adult flies emerged, my suspicion was confirmed.

Using data from life history studies of both species I had conducted under controlled laboratory conditions early in my career, I determined that it would require approximately 2,820 ADH for *Chrysomya rufifacies* to reach the stage of a 15-millimeter-long post-feeding maggot and 2,725 to 2,939 ADH for *Chrysomya megacephala* to develop to a maggot 14 to 16 millimeters long.

Since the two species arrive at a corpse at approximately the same time, this made sense. Usually, *Chrysomya megacephala* arrives a little before *Chrysomya rufifacies*, and I might have anticipated that a few more mature *Chrysomya megacephala* maggots would have been present. One explanation for this lack of larger specimens of *Chrysomya megacephala* maggots might be that *Chrysomya rufifacies* maggots tend to become predators during the later stages of their development and their favorite prey seems to be *Chrysomya megacephala*. To adjust the laboratory data to fit the conditions where the body was discovered, I used temperature data from the weather station at the Kaneohe Marine Corps Barracks less than 2 miles from the site. The temperatures from this station ranged from 24° to 26°C during the period in question. These values resulted in a postmortem interval estimate of approximately 5 days before the discovery of the body.

In addition to the time required for development of the most mature maggots collected, I also took into consideration the different stages of development represented by the maggots of both species. I compared these stages with the results of decomposition studies conducted in a habitat on Oahu similar to that where the corpse was found. In those studies, on the fourth day, there were first, second, and third instar larvae of both *Chrysomya megacephala* and *Chrysomya rufifacies* on the body. On the fifth day, only second and third instars of both species were present, and during the second sampling period of the day post-feeding third instar maggots of *Chrysomya rufifacies* were collected. By the sixth day, only third instar maggots of both species were present on the body. All these data supported the estimated postmortem interval of approximately 5 days before discovery of the corpse.

When the victim was identified, it was clear that the estimated postmortem interval fit the circumstances well. The man had last been seen alive by a relative 5 days before the discovery of the corpse. He had left home for work at approximately 6:00 P.M. and failed to report for work at 8:00 P.M. as scheduled. A suspect was identified and charged with second-degree murder, and he was subsequently convicted when the trial was held in 1989.
Another case demonstrating the importance of the numbers and kinds of insects that succeed the flesh flies and blow flies is that of a corpse discovered in a pineapple field just off the H-2 freeway in Waipio, on Oahu. I was away from the islands on a trip to the mainland when the body was found and could not visit the scene before the body was removed. I did examine the corpse in the City and County Morgue when I returned on the morning of October 16, 1989, and made my collections. The body was in a fairly advanced state of decomposition, and at first even determination of the victim's gender was difficult. The corpse appeared to be between the Post- Decay and Skeletal Stages of decomposition. At the time I made my examination, the corpse was clothed in a tank top and a pair of shorts.

I was struck by the variety of insects on the corpse. Above the right eye, I found a mass of empty pupal cases of the blow fly Chrysomya rufifacies. By the seventeenth day of decomposition in an open pineapple field, all of the specimens would have completed their development to the adult stage and flown away, leaving behind only empty pupal cases; so I was sure that more than 17 days had elapsed since death. I saw several other families of flies on the corpse. I collected third instar larvae of a species of flesh fly that were 15 to 16 millimeters long. Occasionally, flesh flies will deposit larvae on a corpse in the later stages of decay, especially if the surroundings are wet, as they were in this case; so the presence of these larvae was not totally unexpected.

I also found larvae of the cheese skippers on the corpse. After rearing the larvae to the adult stage, I could identify them as Phichilophila casei, a species commonly found on decomposing remains in Hawaii until approximately 36 days after death. The specimens I collected from the corpse entered the pupal stage within 1 day of being placed in the rearing chamber. So I moved the estimated time since death forward to slightly over 1 month. Also on the corpse were maggots of a species of fly in the family Otitidae, the picture-winged flies. These flies are also common during the later stages of decomposition but their maggots are not usually found on a corpse past day 37. One other species was of particular significance: the black soldier fly, Hermetia illucens, which was represented by maggots 10 to 14 millimeters long. This fly does not usually become attracted to a decomposing body until at least 20 days after death; so the presence of such large maggots also indicated a postmortem interval of approximately a month. Given my previous experience with this species in cases and decomposition studies, I suspected that these were not the most mature specimens associated with the corpse. Those would probably have been in the soil under the corpse and might still be at the scene.

The beetles on the corpse also indicated an extended postmortem interval. There were both adults and larvae of the hide beetle Dermestes maculatus feeding on the dried skin and cartilage.
Adults of two species of checkered beetles were also present. The most numerous of these were adults of the red-shouldered ham beetle, *Necrobia ruficollis*, a species I frequently find on corpses, but not usually in large numbers. The other species, the red-legged ham beetle, *Necrobia rufipes*, was also there in large numbers, as is typical for an exposed corpse about a month after death. Since I could see no larvae of either species on the corpse itself, I thought these might still be in the soil. There were also adults of a single species of rove beetle, *Philonthus longicornis*, on the corpse, but no larvae.

A surprising addition to the corpse fauna were a number of immature and adult crickets. These were identified for me as *Teleogryllus oceanicus* by a graduate student in the Department of Entomology who was working toward his doctoral degree on systematics of Orthoptera. I had only rarely encountered crickets on corpses and never before in numbers. Most crickets are omnivorous, and thus it was not surprising to find them their feeding on a corpse, but the numbers in this case were remarkable.

Overall I concluded from my examination of the corpse at the morgue that I was looking at a postmortem interval of slightly over a month, and also that a significant part of the insect fauna had probably not been collected and still remained at the scene. Naturally, there would have been some migration away from the scene once the corpse was removed. But with approximately a month of decomposition, there should have been enough decompositional fluids seeping down into the soil to provide a food source for many of the insects left behind. I definitely needed to visit the scene as soon as possible. With the assistance of the lead detective on the case, I was able to arrange for a supervisor from the pineapple company to meet me at the scene on the afternoon of the sixteenth. This supervisor had been present when the corpse was recovered and could guide me to the exact spot with no difficulty. The site was near the edge of one of the service roads leading into the field and was easily accessible from the main road. The pineapple plants at the site were trampled, probably by the investigators, and discolored, probably by the decompositional fluids leaking from the corpse.

Once at the scene, I could easily tell where the corpse had lain. The soil had a color and texture different from those of the immediate surroundings as a result of the seepage of fluids from the corpse during decomposition, and there was still a strong smell of decay. I immediately noticed large numbers of crickets in the area. These proved to be both adults and immatures of the same species I had collected from the corpse at the morgue, *Teleogryllus oceanicus*. I also collected from the soil a number of rove beetles representing several different species.
Several empty pupal cases of the blow fly *Chrysomya rufifacies* were scattered on the surface of the soil immediately adjacent to the spot where the corpse had lain. These were consistent with the typical pattern for this species—some individuals undergoing pupation on the corpse and the rest migrating away from the corpse to pupate on the soil surface. I also collected adults of the scarab beetle *Aphodius lividus* from the soil in the area where the corpse had lain. As I anticipated, there were a large number of maggots of the black soldier fly, *Hermetia illucens*, in the soil, and these appeared to be in a later stage of development than those I had collected at the morgue. Many of the specimens I thought might be present at the scene are usually found under the surface of the soil rather than on top. To collect these, I took soil samples from where the corpse had lain and the immediately adjacent area, watched by the bewildered pineapple plant supervisor.

On my return to the laboratory in the late afternoon, I put the soil samples into Berlese funnels to extract the arthropods. At the time, I had a small room assigned to my laboratory that had been specifically designed for Berlese processing. It was supposed to be vented directly to the outside of the building rather than connected to the central air conditioning system for the building. At least that was what the building plans said. But by 8:00 A.M. the next morning, it was apparent from a pervasive odor that the vents for this room were actually connected to the central air conditioning system. I was not welcomed with open arms by my colleagues when I arrived that morning.

In a fairly tense atmosphere, I removed the samples from the Berlese funnels and examined them for arthropods. In addition to the maggots I had collected from the corpse, I found larvae of moth flies, in the family Psychodidae, and larger soldier fly maggots. In decomposition studies in wet habitats I had previously seen larvae of psychodids on the corpse during the later part of the Post-Decay Stage. The maggots of the soldier fly were older than those I had collected from the corpse itself, the largest being 23 millimeters long.

There was a greater variety of beetles in the soil samples than on the corpse. In addition to adults of the scarab *Aphodius lividus*, which I had collected from the surface at the scene, there were also larvae in the soil. Although I did not recover any additional species of hide beetles from the soil samples, I did find more species of rove beetles. In addition to *Philonthus longicornis*, there were adults of *Philonthus discoides* and *Thyrocephalus alberti*. And although I did not find any adults of the very large rove beetle *Creophilus maxillosus*, I did find larvae of this species along with larvae of a very small species in the genus *Oxytelus*. The presence of only larvae of these two species was again indicative of a post-mortem interval of just over a month. The presence of only adults of the other three species was consistent with that time period, but not significant in delimiting it. There were also adults of two species of hister beetles in the soil samples, *Atholus rothkirchi* and *Saprinus lugens*, and some histerid larvae that I could not identify to the species level.

In addition to the insects in the soil samples, I found several other arthropods, including a specimen of a tailless whip scorpion. This animal is a very small, soil-dwelling predator, about 1 millimeter long. In Hawaii, it is most commonly associated with agricultural areas. I also identified a symphyllid, an arthropod resembling a small centipede that feeds on plant roots instead of other animals. The samples also yielded several species of gamasid mites. Some were in the family *Macrochelidae*, whose members prey on fly eggs and young maggots. These were definitely related to the corpse, as were the *Uropodidae* mites, which feed on small nematode worms associated with decomposition.

In all, there were 25 different kinds of organisms associated with this corpse and the site of discovery. Not one of these had been actively involved throughout the entire decomposition process, but each of them had played a significant role in decomposition at a specific time.

I was faced with the problem of interpreting this arthropod evidence and putting it into perspective. First I selected decomposition studies whose environmental conditions most closely...
approximated the conditions in the pineapple field, combining data from two studies, one conducted inside Diamond Head Crater and one conducted on the campus of the University of Manoa. Both studies had environmental conditions and arthropod species in common. All of the species and stages of development I collected from the corpse and the pineapple field occurred at these two sites between days 50 and 40 of the studies. To limit this range, I looked at the developmental time required for the black soldier fly, *Hermetia illucens*, to reach the most mature stage collected from the scene and adjusted this according to the temperature data provided by the pineapple grower's weather stations in adjacent fields. This calculation narrowed my estimate to between 54 and 36 days before the discovery of the body on October 15, 1989.

There was some difficulty in identifying the corpse because of the advanced stage of decomposition. When an identification was made based on dental records, the victim proved to be a man who had been reported missing on September 15, 1989, and had last been seen alive on September 8, 1989. His blood-stained truck had been found in a parking lot on September 13, 1989. It had been 36 days between the last sighting of the man alive and the discovery of his body.

Pacific Ocean. The Honolulu Police Department personnel who recovered the body said that the skeletal remains were thinly covered with dirt and gravel, with some bones exposed and scattered on the surface. Four small stuffed dolls had been buried along with the body.

My examination of the remains took place on Monday, June 25, 1984, at the City and County Morgue. Because of the apparent absence of insects on the skeleton, the medical examiner did not at first think that I would be able to contribute much to the investigation, but he nevertheless contacted me and asked me to examine the remains.

When I saw the skeleton I immediately realized that the medical examiner had missed some very significant items in his assessment of the level of insect activity. Only a few types of insects

*in the previous two cases, I used the presence of species and stages of development to estimate the time of death. I have also encountered cases where the absence of life stages for a species proved to be a key piece of evidence. In one such case I was faced with the skeletal remains of a child approximately 50 months old, recovered from a grave on the side of Koko Head Crater on the island of Oahu on June 24, 1984. The child, a little girl, was buried on a small ledge overlooking Hanauma Bay and the*
were present, but these still could provide some information about the death. The little girl had been buried in a pink hooded jacket and a pair of pink running shoes, clothing that assisted police in the initial presumptive identification of the victim. The hood of the jacket had been pulled close around the head when the remains were discovered, and it contained soil and by-products of decay from the skull. While examining the skull, I discovered under the remains of the scalp a number of empty pupal cases of the blow fly Chrysomya rufifacies, but no intact pupae. They indicated a postmortem interval of over 17 days. There were also adults and cast larval skins of the hide beetle Dermestes maculatus on the skull, but I could find no larvae or pupae of this beetle anywhere on the remains. Looking at the bases of the hairs on the scalp, I found larvae of a species of window fly, in the family Scenopinidae. In Hawaii, larvae of scenopinids are not commonly found on decomposing remains in dry conditions until 40 days or more after death. The specimens I collected were as large as those recovered from pigs on days 48 to 51 in studies I had conducted inside Diamond Head Crater. The child's right foot was still in a running shoe and was partially mumified. On this foot, I found an adult red-legged ham beetle, Necrobia rufipes, and an adult hister beetle, Sphagus lugens.

In addition to the specimens I was able to collect from the skeletal material, there were also the soil and decomposition by-products in the hood of the jacket to consider. I took this material and first examined it under a dissection microscope in my laboratory and then put it into a Berlese funnel for 48 hours to collect the microscopic specimens still in the soil. Under the dissection microscope I was able to discern additional empty larval skins of the dermestid beetles and some more scenopinid larvae. The Berlese funnel collection yielded more specimens of scenopinid larvae and a number of different species of mites. There were several predatory species of mites, including two in the family Macrocheilidae, which feed on fly eggs and larvae as well as small soil-dwelling arthropods. There were two species of mites, Macrocheles medarius and Glypholaspis americana, represented only by adult females. I also found immatures and adults of species of mites in the family Uropodidae in the sample. These mites commonly feed on roundworms associated with decomposition. The soil under the corpse also contained the mites Tyrophagus putrescentiae, an unidentified species of the genus Histiozoa, and Czespinnia transversostriata, all of which feed on by-products of decomposition.

My analyses of this assortment of species gave a preliminary estimate of 51 to 76 days between death and the recovery of the specimens from the remains. I then began to examine the patterns of activity and occurrence of stages of insect life cycles more closely. The larval scenopinids indicated a time period of from 48 to 51 days. The last larvae of Dermestes maculatus found in any decomposition studies conducted in similar habitats were collected 51 days after death. The presence of only adults of the two species of Macrocheilidae was consistent with an interval of between 22 and 60 days. I estimated a total of 97 mites per milliliter for the sample from the hood of the jacket. According to decomposition studies this number was consistent with an interval of between 48 and 51 days, and the number of Acaridae in the samples indicated a period longer than 48 days. In the final analysis, the most significant factor proved to be the absence of larvae of Dermestes maculatus and the condition of the cast larval skins. In decomposition studies conducted in similar habitats, the last larvae had been observed 51 days after death. Once the larval skins are shed, they are quite fragile and degenerate rapidly if exposed to the elements on the soil surface. The cast skins I collected were in excellent condition and I could easily make a species-level identification. Their condition indicated a short period of exposure, and my estimate of the postmortem interval was slightly over 52 days.

In the meantime the police investigators had been busy dealing with conflicting statements about the crime. On May 3, the little girl's father reported that his daughter had been kidnapped by two men who arrived at his apartment on the night of May 2 and forced him and his daughter into a car. The father said they
were then driven to the Chinatown area of Honolulu, where he was taken out of the car and beaten by one of the men. The two abductors then drove off with his daughter. The father was treated at a local hospital for injuries sustained in the beating. These events would have occurred 51 days before the discovery of the body. When the news media picked up this story, two men came forward and said that they had, in fact, beaten the father, but that the father had paid them to do so. They were usually willing to perform that service without compensation, but since they were being paid they did an exceptionally thorough job, thus landing the man in the hospital.

Confronted with this testimony, the father changed his story. He now said that he took his daughter hiking along the cliffs at Koko Head Crater on May 2, and while hiking he slipped and dropped the child over a 10-foot cliff. He climbed down to the ledge and found the girl still breathing, but unable to move. As he sat with her, her breathing and heartbeats became weaker. He could not revive her and she died. He then buried her in a shallow grave nearby. The next day, fearing prosecution, he reported the kidnapping. The police did not believe the accident story and issued a warrant for the father’s arrest on a charge of murder.

Following his arrest, the father gave several different versions of the death, and by the time the case came to trial, the only aspect of it that had not changed significantly was my estimate of the time of the death. Both the prosecution and defense lawyers were happy with this estimate, because it suited both of their strategies.

In my first appearance in a criminal court, I had to convince a judge and jury that a significant aspect of a murder could be explained by looking at the empty skins of beetle larvae. Not only was this my first court appearance as an expert witness, but it was the first time entomological evidence had been introduced in a homicide trial in the state of Hawaii. In many respects, this was an ideal first case. Both sides wanted me to establish exactly the same time of death—the only time this has happened in all my courtroom experiences. Initially subpoenaed by the defense,

I was also consulted by the prosecution. During meetings with each side, I explained to both attorneys the basis for using insects and other arthropods as indicators of the postmortem interval, the techniques I had used in conducting decomposition studies, and how I had arrived at my conclusions in this case. After these meetings, I felt relatively confident, and arrived at court with few apprehensions. After all, both attorneys wanted the same basic testimony. But this confidence was soon shaken.

First I needed to be qualified as an expert in entomology. For some reason, just having a Ph.D. in the field was not sufficient. I was then still quite naive about courtroom procedures. All my education, professional experiences, and publications had to be presented to the court. I had supplied each attorney with a copy of my curriculum vitae, and essentially they took turns reading this to the court. No one, including the judge, had any idea of what constituted entomological competency. By the end of the first hour, I wasn’t sure I was qualified to tell the time of day. Four hours later, it was decided that I was in fact a qualified expert in the field of entomology, and I began my testimony.

Unfortunately, as I began to testify, it dawned on me that neither attorney had any idea what I was talking about, except for the fact that insects were somehow involved and I had come to a conclusion with regard to the time of death. Then there was the unanticipated problem with the court recorder. Most of the words I was using were not in her dictionary, and I spent a good deal of my testimony time spelling scientific names for the record. I presented my results relatively quickly and cross-examination was minimal and friendly because the lawyers each wanted my estimate to be believed. But even with an agreed-upon date of death, the father’s version of events was not accepted by the jury. He was convicted of murder and is currently serving a life sentence.