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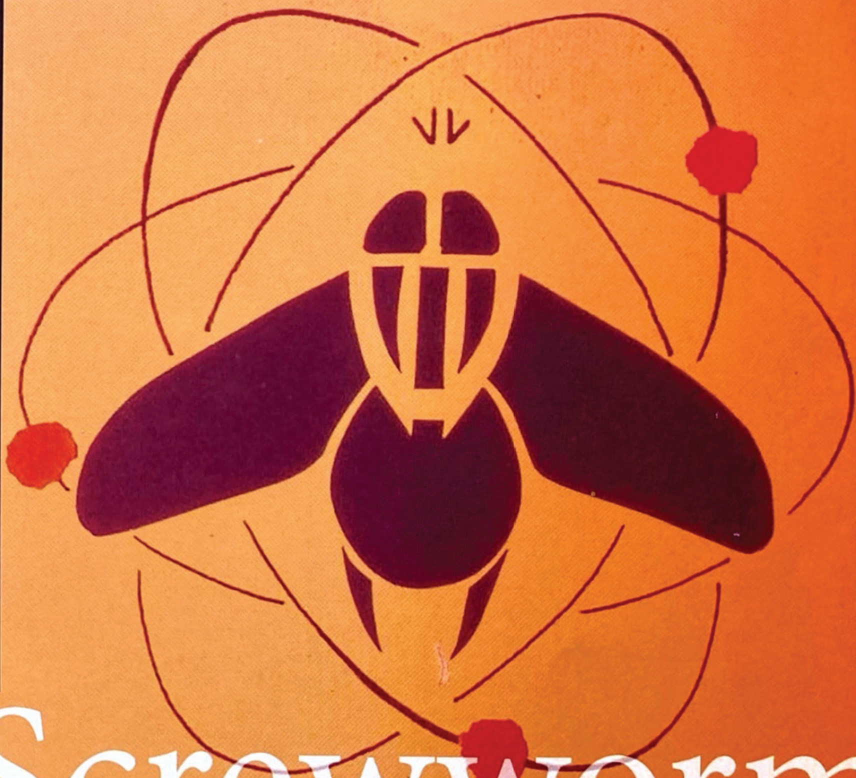

Screwworm Eradication

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Front cover: The emblem for the U.S.D.A. screwworm eradication project using radiation to sterilize the flies.

Photo credits: Unless otherwise indicated, all photos are from the U.S.D.A. slide series released at the time of the screwworm eradication. These can also be found at the U.S.D.A. special collections website for audiovisual materials: Screwworm Eradication Program Materials (see references). Outline map (Figure 11) of progression of eradication through North America is from the Food and Agriculture Organization (see references) as is map on page 13. The outline map of the 1963 barrier zone (Figure 23) is from "Facts About Screwworm Eradication" January 1963 by the USDA ARS.

Screwworm Eradication

INTRODUCTION

Ask a retired rancher from the southern United States about the "screwworm fly." You will hear the story of a heroic effort where ranchers and scientists worked together to eradicate a major insect pest from North America. It is a story of entomologists who took a new and creative idea from theory to practice. It combined the skills of manufacturers, food processors, airplane pilots, radiation specialists, veterinarians and field technicians.

It has prevented much animal suffering in both domestic and wild animals. The screwworm eradication not only made the cost of our meat cheaper, the success of this procedure has major implications for food supplies worldwide.

And like much successful science, the absence of this pest and the resulting benefits have been, for the most part, forgotten.

WHAT IS THE "SCREWWORM FLY"?

In 1775, the famous entomologist Fabricius assigned the name *Cochliomyia macellaria* to a fly belonging to the family Calliphoridae. These blow flies inhabit animal wounds. He coined the term "screwworm" due to the screw-like shape of the larvae that burrowed into the animal. Only in the 1930's did researchers discern that the screwworms that fed on live tissues and caused dramatic damage were a distinct species from *C. macellaria* that fed only on dead tissues. This unique blow fly had been named *Lucilia hominivorax* by Coquerel in 1858. Because it was soon recognized as belonging in the older genus *Cochliomyia*, this primary screwworm is now named *Cochliomyia hominivorax* (Coquerel, 1858).

HOW IS THE SCREWWORM HARMFUL?

It was a gruesome infection. From pioneer days until the mid-20th Century, the North American screwworm was a scourge of cattle. Any little cut from thorns, any open wound left from birthing, any eye infection that wept, and any small cut from barbed wire would soon harbor the larvae of the dreaded primary screwworm.

The adult female fly is attracted only to living flesh. The eggs she laid hatched into maggots that burrowed into the wound. Their feeding and secretions expanded the wound, providing more space for more eggs. What began as a small innocuous cut soon grew into an extensive infection that caused much suffering and could soon kill the animal.

Figure 1. The wound that began as a cut on the eye of this animal rapidly expands.

Figure 2. U.S.D.A artist view of female screwworm laying eggs in living wound.

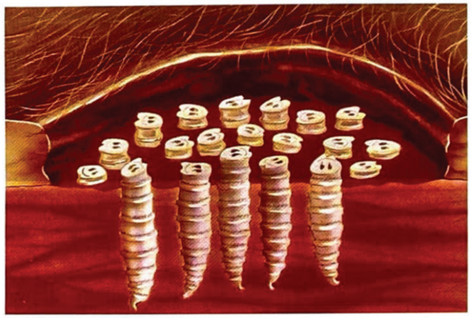

Figure 3. U.S.D.A. artist view of larval screwworms embedded in wound.

WHAT IS THE FLY'S LIFE CYCLE?

To control the primary screwworm, it was critical to understand the basic biology and life cycle of the organism. Because a life cycle is continuous, we could start at any life stage. We begin with the adult.

Once the female screwworm has mated, she searches for a host. She must lay her eggs on an open wound of a cow, horse, pig, deer, sheep or other mammal. She deposits her eggs during the 7th to 9th day of her short 10-30 day adult life.

The raft of eggs will hatch in 12–14 hours and the small larvae (fly larvae are often called maggots) will burrow downward into the wound. Rings of small setae (spines) pointing backwards like fishhooks keep the host animal from digging the larvae out of the wound. The heads of the larvae are pointed downward. Their tails are the blunt end at the surface of the wound. This screw-shape gives them their name. Two eye-like spiracles let them breathe. As the larvae grow, they secrete chemicals onto the surface of the wound that expand the wound, and other female flies can deposit additional eggs that hatch larvae to expand the wound. Larvae feed and grow in the wound for up to 168 hours.

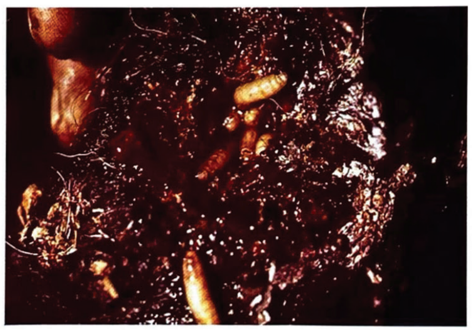

Figure 4. Excised wound showing maggots in infected tissues.

Fully grown larvae fall to the ground and snuggle into the soil just below the surface. They now change into the pupal stage. Similar to the process where caterpillars metamorphose into moths, the maggots will re-build their bodies into adult flies. At the end of about 7 days, the adult fly will emerge from its pupal case (puparium or larval skin) and crawl above the surface of the soil. To "pop" the top of their pupal case off, the fly inflates a temporary head sac, similar to a car air bag. At the surface of the soil, the newly emerged adult fly rests briefly to inflate its new wrinkled wings.

The various stages have temperature requirements. The egg and pupal stages require a warm 27°C (80°F) for normal development. The larvae in the wounds are even warmer. The fly is not cold-hardy; the screwworm's range was limited to the southern United States, pushed south when the winter was colder and surviving further north when winters were mild.

However , the rapid life cycle of the screwworm allowed it many generations each summer to expand and move dramatically northward. This northward summer expansion was aided by the migration of the host livestock.

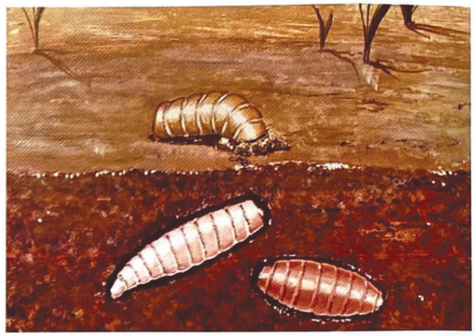

Figure 5. Artist representation of screwworm larvae burrowing into soil. (U.S.D.A.)

Figure 6. Artist view of adult flies emerging from pupal cases. (U.S.D.A.)

Figure 8. U.S.D.A. graph showing one complete life cycle.

Figure 7. Photo of emerging fly showing its balloon-like device (ptilinum) for popping off the lid to the pupal case.

Figure 9. Ranchers spray their livestock. It was important to maintain conventional controls while conducting the sterile release.

Figure 10. Wild animals such as deer also harbored screwworm infestations, providing a reservoir of untreatable animals.

Figure 11. The general summer expanded range of the screwworm and the approximate frontlines of eradication by years (U.N. F.A.O.)

WHY DID CONVENTIONAL CONTROL NOT WORK?

Ranchers use many methods to control parasites and diseases in their livestock because they have the greatest motivation to keep their animals as healthy as possible. Ranchers sprayed their cattle and ran animals through "dips" to suppress parasites. Veterinarians took care to medicate wounds caused by birthing, castration, and other procedures. However, whenever cattle suffered natural cuts and wounds on the range, the screwworm fly was there to deposit eggs and the expanding wound might go unnoticed until it was fatal.

The screwworm fly laid eggs not only on cattle and sheep and pigs, but also on wild animals including antelope and white-tailed deer. Up to 75 percent of newborn deer died from these infestations. Even if ranchers treated all of their livestock in a massive coordinated campaign, the infected wild animals would always provide a reservoir to re-infect their herds.

WHAT IS "STERILE RELEASE"?

Two U.S.D.A. scientists, Edward F. Knipling and Raymond C. Bushland, recognized that the screwworm fly had a vulnerability: she only mated once but the males mated many times. In addition, it was becoming known that radiation could cause sterility. In 1937, they published their theory that by raising huge numbers of sterile flies and releasing them, it might be possible to eliminate a local population and perhaps even drive it to extinction.

A small field trial was conducted on Sanibel Island off of the coast of Florida. It was successful but was readily reinfested from the Florida mainland only 3 kilometers away.

A larger trial was then conducted on the island of Curacao in the Netherlands Antilles. The flies were totally eradicated in less than 6 months.

WHAT IS THE MATHEMATICS OF STERILE RELEASE?

Since females only mated once, if we can swamp them with an equal number of sterile flies, half of the matings would produce sterile eggs and the next generation would be cut in half. Overwhelming the next generations with more sterile flies would eventually reduce the number of fertile flies to so few that a fertile female would not locate a fertile male—and the species would go "locally extinct".

HOW CAN WE RAISE MILLIONS OF FLIES?

Knipling and his U.S.D.A. colleagues working in the Agriculture Research Service and the Animal and Plant Health Inspection Service faced a huge research project—trying to raise flies to kill flies.

As can be seen in Figure 11, they began the actual U.S. eradication starting in the eastern United States in Florida, and pushed the line of eradication westward and then south into Mexico. The first "fly factory" was built at Sebring, Florida in 1958.

For the major portion of the U.S. effort, the flies were raised and sterilized at a plant in Mission, Texas (Figure 12). Built on a former Air Force base in 1962, it supplied the huge number of flies needed for the eradication program. This plant was built in part with funding from the stockmen and Southwest Animal Health Research Foundation.

To produce up to 140 million flies a week required a huge operation with 75,000 square feet of floor space. There was no air conditioning because the temperature had to be kept at the warm outside temperatures where the flies would breed. Much research had to be conducted to feed happy flies and keep them healthy.

MENU TO FEED 140 MILLION FLIES

Beef and pork lungs.....200,000 lbs.
Dried blood..................11,000 lbs.
Horsemeat.......................8,500 lbs.
Non-fat dried milk...........2,700 lbs.

Mix until blended (Figure 14). Add preservatives. Maintain moisture. Provide to fly larvae in shallow trays. Keep at 100°F approximating the temperature of wounds in animals.

ASSEMBLY LINE FLY PUPAE

When the larvae finish feeding and are mature, they begin to crawl from the rearing trays. They are then placed in trays and allowed to burrow into shallow sawdust.

Factory assembly line equipment was modified to separate the larvae at different stages and package them for irradiation and airborne delivery.

By the time the dormant screwworm pupae reached 5 ½ days old, they were exposed to Cobalt-60 gamma radiation for just the right amount of time to cause sterility but not affect the flight or mating behavior of the flies. Both male and female flies were sterilized.

The U.S.D.A. was careful to explain: "...they are not radioactive and so present no radiation hazard to people, animals, or plants. Measured numbers of irradiated pupae are placed in cartons...."

STERILE PARATROOPERS

These sterile flies were packaged in loose cardboard boxes and loaded into specially built cargo planes. The planes then flew a precise pattern along the barrier zone frontline. Again, the U.S.D.A. describes: "The airplanes are equipped to drop the flies automatically at predetermined intervals and at rates required to overwhelm native screwworm populations." Sometimes planes would backtrack to hit "hot spots."

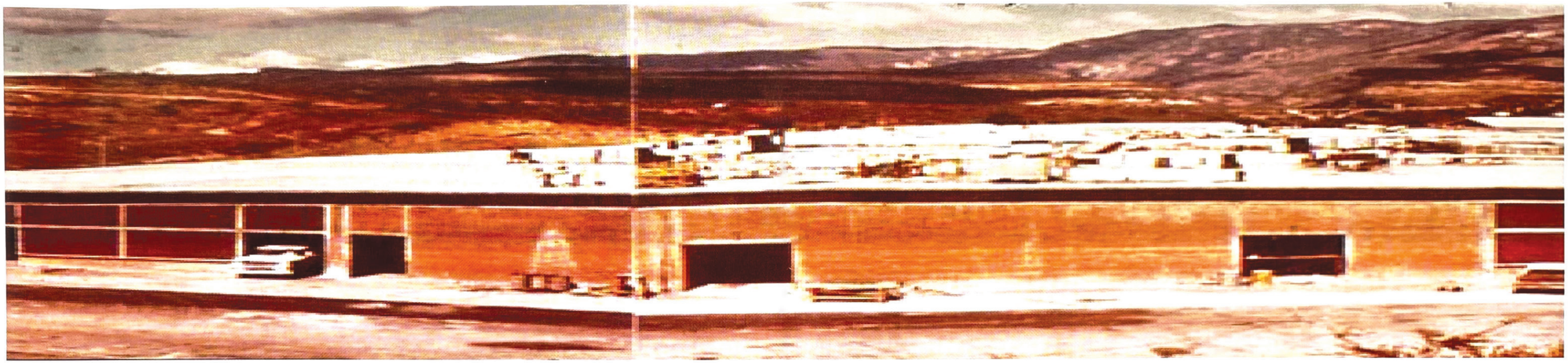

Figure 12. Screwworm rearing facility at Mission, Texas in 1960s. The plant was disassembled after eradication was achieved.

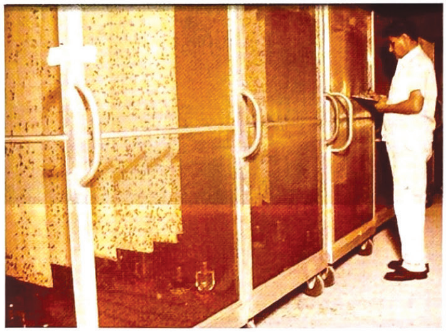

Figure 13. Adult flies rest on vertical sheets.

Figure 14. Chef mixes up daily diet for larvae.

Figure 15. Continuous care is required to keep larvae healthy.

Figure 16. Larvae feeding on special diet.

Figure 17. Pupae in sawdust before irradiation.

Figure 18. Pupae are separated from sawdust.

Figure 19. Boxes of irradiated pupae loaded into plane.

Figure 20. Precision air drops advance the barrier zone.

Figure 21. Sentinel sheep were critical in determining if any screwworms remained.

HOW TO MEASURE "SUCCESS"?

The key to the process was knowing when there were no more fertile flies; the eggs laid in wounds did not hatch. Only then could they move the barrier zone forward. Since the adult screwworm fly only comes to open living wounds, not to dead meat, it was necessary to use "sentinel" sheep with open wounds—purposely inflicted cuts—in order to detect if there were any wild flies left. No other system would work.

Just as we know that we have to suffer the momentary pain of a vaccination in order to avoid the much greater suffering of serious infectious diseases, a number of sentinel sheep had to endure surface wounds in order to wipe out the screwworm fly. For those who would never condone this very limited suffering by the sentinel sheep, they must consider that inaction would have allowed the ongoing and far more massive suffering of both domestic and wild animals in the future. Today, researchers are trying to formulate a "bait" that will simulate the attractants found in real wounds to replace sentinel sheep, but that would be little justification for 50 years of inaction.

It is important to understand that the biggest benefactors of agricultural research using animals—are the animals themselves.

Figure 22. Many technicians were necessary to identify specimens and distinguish the screwworm from other similar but harmless species.

PESTICIDES VS. STERILE RELEASE

One brilliant insight of Knipling and his colleagues was that sterile release had a potential to drive a species extinct while pesticides could not.

In spite of huge human effort and expenditure of massive amounts of money, pesticides used on insects such as mosquitoes and major crop pests have failed to eliminate even one pest species.

Although new pesticides may kill more than 99% of a pest species on first application, time and again there have been a few survivors who have an enzyme to break down the chemical or have other methods to survive. The survivors that were not affected by the pesticide rapidly build up populations to consume the monoculture crops we put before them, often in higher numbers since the pesticides often knock down the insect predators that take longer to recover.

However, sterile release uses the insect's own reproductive vulnerability of only mating once to drive it to "local extinction" (extirpation). It is far more difficult for a pest to evolve an alternative to its own reproduction.

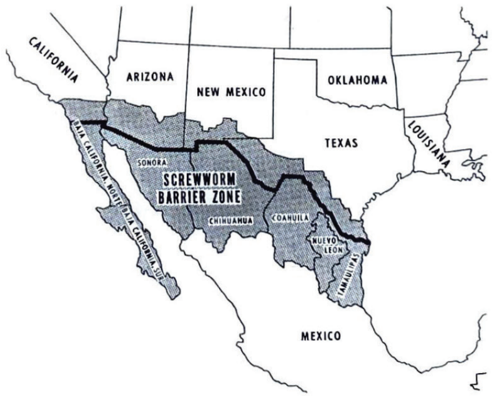

Figure 23. Approximate barrier zone where progress came to a halt.

PROBLEMS ON THE BORDER

After initial success in moving the barrier zone across the United States from east to west, the effort soon came to a halt in 1968. While there are many factors affecting the speed the screwworm could be eliminated, the effort was nearly dead-stop.

Despite continuous air drops of sterile flies along the barrier zone, the sentinel sheep remained as infected as ever. What was not working?

Richardson et al. (1982) detailed one potential problem. With considerable ecological work, entomologists thought that the variety of screwworm that had been so successful (Type "F") did indeed drop to zero when a new area was bombarded with sterile flies. But other screwworm flies (Types "D" and "I") were thought to increase and "fill in," keeping the screwworm population at full levels. Further examination of these "types" revealed slight variations in their genitalia and suggested that they did not all mate randomly with each other. There was also evidence that some of these variations within the species might be local variants that were well-adapted to local conditions. Yet they could still interbreed and remain one species. They just did not often mate with the sterile Type F.

To make a complex situation simple, by incorporating breeding stock from in front of the barrier zone, a mixture of screwworm "types" could be dropped and the screwworm eradication now moved ahead.

Unless the screwworm was eradicated from Mexico, there would always be a threat of reintroduction. And the barrier zone would have to remain in place. So the eradication was continued south through Mexico. The U.S. also airlifted sterile flies to Puerto Rico and adjacent islands. By the end of 1984, Mexico north of the Isthmus of Tehuantepec was free of screwworm and the plant at Mission Texas was closed.

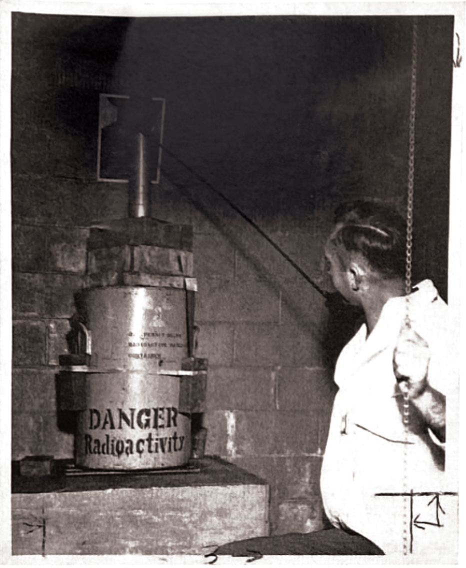

Figure 24. The very simple source of Cobalt-60 used in the first screwworm plant in Sebring, Florida.

WHAT RADIATION DOSAGE LEVEL?

One very early question that had to be answered concerned the dosage of radiation that should be administered.

This was not a simple task. If the dosage was too weak, the flies that were released would contain many fertile specimens and make the screwworm problem worse. If the radiation dosage was too strong, the flies would definitely be sterile but it might also make the screwworm adults "sick" so they did not fly well nor behave normally in order to mate with wild flies.

It must be remembered that Watson and Crick had only just discovered the structure of DNA in 1953 and that the biological effects of alpha, beta and gamma radiation were not well understood. This trial-and-error work in physics was just one part of the wide-ranging applied research involved.

MODERN RADIATION BIOLOGY

Today we understand the reasons why reproductive cells are more easily damaged by gamma radiation than are neurons that determine behavior.

In 1906, Bergonie and Tribondeau discovered that cells were most sensitive to radiation if they are: rapidly dividing, undifferentiated and have a long mitotic future. At that time, Gregor Mendel's basic genetics had barely been rediscovered and DNA was completely unknown.

Evidence from Hiroshima and Nagasaki as well as subsequent cases of radiation sickness indicated that some body tissues are more easily damaged. The most vulnerable were clearly the epithelial cells of the skin and digestive tract lining as well as reproductive cells. However, brain and muscle cells appeared to suffer less damage. Today we know that there is a range of sensitivity to radiation.

Increasing Sensitivity to Radiation

↑
- Reproductive cells
- Blood cells
- Epithelial cells
- Endothelial cells
- Connective tissue cells
- Bone cells
- Nerve cells
- Brain cells
- Muscle cells

While the factors are more complex, this scale confirms Bergonie and Tribondeau's early observation. It is harder for ionizing radiation to hit and damage DNA when it is dispersed than when it condenses into chromosomes in a reproducing cell. Thus a dosage of gamma radiation that damages sperm and egg production does less damage on neurons. Without this difference, the sterile release system would not work.

THE MEDFLY

The Mediterranean fruit fly (called "medfly"; scientific name *Ceratitis capitata*) is a fruit fly that causes devastating damage to many fruit crops. It was native to the Mediterranean area but can invade and destroy fruit crops around the world.

Similar to the primary screwworm fly, the medfly mates once. It can also be reared and sterilized. Sterile insect technique can be used to rapidly eradicate invasions if caught early.

To keep medfly out of the United States and Canada, bait traps specific to medfly are arrayed around airports in the fruit-growing regions. The medfly has attempted to invade Texas, Florida and California with re-introductions occurring in 1981, 1989, 2007, 2008 and 2009. Each time, sterile release has succeeded in eradicating the medfly, using one million sterile adult flies dispersed in the infested area per square mile per week. When the invading population gets too large, it is also necessary to reduce it using insecticides before sterile release can be effective, as was the case under Governor Jerry Brown in 1981 in California. The medfly has also been eliminated from Chile and New Zealand using sterile release.

THE LIBYA EMERGENCY

The primary screwworm is only native to the Americas and had been driven to south through Mexico by the sterile release technique. But in 1988, this New World screwworm was discovered in the Arab Jamahiriya in Libya.

The production of livestock in Africa faces many challenges and the addition of this pest would be a disaster to the whole continent. The FAO estimated that the cost of control in North Africa alone could be US$250 million per year. Since the screwworm infests wildlife as well, the damage to wildlife south of the Sahara could result in extinction of some wild species.

The only real solution was to import sterile flies from the screwworm production plant located in Panama.

Air drop of sterile screwworms began in December 1990 with 3.5 million flies released per week. This increased and by April 1991, 28 million sterile flies were being released over the screwworm-infested area twice a week. Eventually about 1000 sterile flies per square kilometer were released, exceeding the density used in Mexico.

1991 saw the last case of the New World screwworm in Libya—another success for the sterile insect technique.

EDWARD F. KNIPLING

Edward Fred Knipling was born near Port Lavaca, Texas on March 20, 1909. As with most field biologists, he was a farm boy and developed his early interests in insects and animal behavior in the field. Knipling studied entomology at the Agricultural and Mechanical College of Texas (now Texas A&M University). After receiving his bachelors degree in 1930, he completed his masters degree in entomology at Iowa State College (Iowa State University) in 1932 and later earned his doctorate from there in 1947.

Knipling's whole career was with the U.S.D.A., rising in responsibility to eventually become Director of the Entomology Research Division at the Agricultural Research Service headquartered in Beltsville, Maryland. During World War II, he was Director of the Orlando Laboratory on Emergency Research to protect Allied troops from insects that vectored malaria, typhus, and plague.

In 1938, Dr. Knipling developed the idea that certain insect populations with mating limitations could be controlled by raising them in huge numbers, sterilizing them with the new radiation technology, and flooding the wild populations. It was only after World War II that Knipling and longtime colleague Raymond C. Bushland were able to secure an old Army X-ray machine to determine if the screwworm fly could be sterilized. They faced skeptical superiors who were accustomed to only using insecticides. Their first batch of sterilized flies were released on Sanibel Island in Florida and proved their theory.

In addition to the success story described in this issue, Knipling's sterile insect technique was successful against the Mediterranean fruit fly and reduced the tsetse fly, the vector of sleeping sickness in Africa.

Edward F. Knipling and Raymond C. Bushland together received the World Food Prize for 1992 that "recognized a team of entomologists who gave the world an environmentally friendly means of controlling insects that threaten the production of crops and livestock. With global population growing by over 95 million people a year, effective control of pests is crucial to preserving the world food supply."

Known as "Knip" by his friends, Knipling always kept his childhood interest in entomology. Many colleagues related: "What he really loved to do, he loved to sit down and talk insects."

Edward F. Knipling, who carried through this revolutionary approach in pest control, died on March 17, 2000 at his home in Arlington, Virginia.

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Healthier cattle face **a western sunset.** The American livestock industry "benefits by more than $900 million a year as a result of the eradication of the screwworm" according to U.S.D.A estimates. This market value does not include the improved human and livestock health, benefits to wild species, increased standards of living, or the prior man-hours lost to treating affected livestock.