Baumhover: A Personal Account of Screwworm Eradication

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A PERSONAL ACCOUNT OF PROGRAMS TO ERADICATE THE SCREWWORM, *Cochliomyia hominivorax*, IN THE UNITED STATES AND MEXICO WITH SPECIAL EMPHASIS ON THE FLORIDA PROGRAM

ABSTRACT

The great saga of the eradication of the screwworm first from Curacao and then from all of North and Central America is recounted with special emphasis on activities in Curacao and Florida from 1951 through 1957. The author, who worked as a research scientist on all aspects of laboratory and field research and operations, brings to light many biological and operational problems along with corresponding solutions, which are not treated in the published accounts of USDA administrators involved in these programs.

Curacao served as a 170 square mile outdoor laboratory for developing the sterile insect technique. This setting permitted quantitative determination of the dynamics of the wild population, and the overflooding ratios and dispersal patterns essential for population suppression. The attack on the wild population during the time of year when it naturally undergoes decline proved to be essential in achieving eradication with minimal resources.

The Florida programs yielded three extremely important findings. The first is that eradication is greatly facilitated by taking advantage of severe weather events which reduce the range and density of the target population. Secondly eradication cannot be readily attained merely by the release of sexually sterile insects, since it is absolutely essential that producers simultaneously attack the immature stages by diligent inspection and treatment of wounds. Thirdly the leadership of the producer clientele is critically important to securing program resources from livestock owners, the State Legislature and the Congress. These lessons were corroborated repeatedly as the program dealt with the southwestern USA, Mexico and the Central American countries.

Key Words: Screwworm, *Cochliomyia hominivorax,* sterile insect technique, eradication, Curacao, history

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RESUMEN

Se hace un recuento de el primer programa de erradicación del gusano barrenador del ganado en Curacao y luego en Norteamerica y Centroamerica, con especial enfasis en las actividades realizadas en Curacao y Florida desde 1951 hasta 1957. El autor de este artículo, quien trabajó como científico investigador en todos los aspectos relacionados con investigaciones de laboratorio, campo y como coordinador de operaciones, da a conocer los pormenores de los problemas biológicos y de operación de este programa, así como también de sus soluciones, las cuales no se han sido discutidas en ninguna de las publicaciones administrativas de estos programas del USDA .

El area de 170 millas cuadradas del territorio de Curacao sirvió como laboratorio para desarrollar el programa de tecnicas de insectos esteriles. Esto permitió que se realizara una determinación cuantitativa de la dinamica poblacional de la población salvaje del insecto, y del area adecuada para liberar proporciones elevadas de la población esteril los cuales ayudaron a establecer patrones de dispersión esenciales para la supresión de la población. Efectuar liberaciones de insectos esteriles en la epoca del año cuando la poblacion natural está en declive, fue un factor esencial para lograr la eradicación en un programa que contaba con recursos mínimos.

Tres resultados muy importantes fueron encontrados a traves de los programas realizados en Florida. El primer resultado demostró que la eradicación se facilita enormemente al realizar liberaciones cuando hay cambios climaticos severos los cuales reducen el rango y densidad de la población del gusano barrenador. Segundo, la erradicación no puede ser lograda unicamente por el hecho de liberar insectos sexualmente esteriles, sino que es esencial que los ganaderos controlen oportunamente los estados inmaduros del gusano, efectuando un monitoreo y un tratamiento constante de las heridas causadas por el gusano. Tercero, el liderazgo que tome la clientela de los productores es esencialmente importante para asegurar que hayan recursos que provengan de los ganaderos, la Legislatura estatal y del Congreso de la Nación. Estas lecciones fueron corroboradas repetidamente cuando el programa tuvo que realizarse en el suroeste

de los Estados Unidos de America, en Mexico y en los países centroamericanos.

The screwworm, *Cochliomyia hominivorax (Coquerel)*, is an obligatory parasite of living warm blooded animals, including man. It has a life cycle of about 21 days during periods of warm weather. The female oviposits on any lacerated or bloody areas caused by fighting, barbed wire scratches, castration, dehorning, branding, ticks, and on body openings with fetid odors. Moreover, the tender navel area of newborn animals is particularly attractive. Unless the infested wound is treated with an insecticide, flies will continue to oviposit on their host until near death (Fig. 1). Laake et al., 1936, has provided a detailed description of the various life stages, economic importance, distribution, etc. The various life stages are shown in Figs. 2 - 5.

The screwworm survives only in mild climates such as those suitable for growing citrus (Fig. 6). Its overwintering area in the USA varied with the severity of the winter. During a mild winter, it survived as far north as Oklahoma in the Southwest, and in the Southeast as far north as the lower third of Georgia and South Carolina. The average overwintering zone was 50,000 square miles each in Texas and Florida, with much smaller areas in California, Arizona, and New Mexico.

Fortunately, a severe winter in 1957-1958 eliminated screwworm activity above a line extending from Tampa, Florida, to Vero Beach, Florida. As will be shown later, screwworms were eradicated in Florida and the Southeastern United States in less than one year instead of the two years anticipated if screwworms had survived in the average overwintering area below Jacksonville, Florida. Indeed if the program had started following a mild winter, three years may have been required to eradicate.

The sterile male technique involves mass rearing the parasite, irradiating them late in the pupal stage with gamma rays (Figs. 7 - 19), and releasing the adults usually from aircraft (Fig. 20) to compete with wild males in nature. Wild females mated to released males oviposit normally, the embryos initiate development, but die before hatching. Economic losses in Florida prior to eradication were estimated at $20 million annually.

PRE-CURACAO

Knipling (1997) first conceived the idea of sterile insect technique for suppressing screwworm flies in 1937. He visualized that the sustained area-wide release of large numbers of sexually sterile males into the wild population would eliminate their reproduction and lead to their eradication. As a fledgling entomologist Knipling's proposal was not seriously considered by his superiors in the Bureau of Entomology and Plant Quarantine, U.S. Department of Agriculture, but the idea remained firmly in his mind and was discussed repeatedly with his close colleagues, Dr. A.W. Lindquist and Dr. R.C. Bushland. During World War II, Knipling and Bushland both worked on projects to protect the armed forces from arthropods and arthropod-borne diseases. As a result, their follow up on this innovative concept was delayed. However after the War, as Knipling rose rapidly through the Bureau's ranks, he was able to secure limited funds to research his idea. Bushland (Melvin and Bushland, 1935) had already fulfilled one of the requirements of the sterile insect technique by developing an artificial diet for the screwworm. The diet consisted of a mixture of ground lean beef, blood, water and 0.2% formaldehyde to deter decomposition. Previously screwworms had been reared on rabbits or baby calves, a very nasty and cruel procedure. To induce sexual sterility various chemicals were evaluated, but none was found effective. However, H. J. Muller (1950), reported in the *American Scientist* that exposure of Drosophila to high doses of x-rays induces dominant lethal mutations in the germ cells. These mutations prevent the development of the embryo, and thereby cause sexual sterility. A.W. Lindquist read this popular article aimed at swaying public opinion against atmospheric tests of atom bombs and showed it to Knipling. Knipling corresponded with Muller, and Muller expressed confidence that ionizing radiation would induce sterility in the screwworm. Indeed Bushland and Hopkins (1951, 1953) observed this same effect when screwworm life stages were exposed to x-rays or to gamma rays from Colbalt^{60} (1953). They showed in laboratory cage tests that sterile screwworm males were able to compete with normal males in mating with untreated females. Since the screwworm female mates only once, all egg masses laid by a wild female who mated with a sterile male are non-viable.

In order to assist in evaluating the performance in the field of irradiated sterile males, I was reassigned from the USDA Grasshopper Control Division, first to the USDA's Insects Affecting Man & Animals Laboratory, Kerrville, Texas, and later to a sub-laboratory at Orlando, Florida. Prior to my transfer, Bushland had made an attempt to evaluate the field performance of irradiated screwworm males on the shoals of Texas near Austwell. This effort had failed apparently because the released flies were carried by the prevailing winds to the mainland. In any case no egg masses were laid on wounded sentinel goats. Subsequently during the winter of 1951-1952 efforts were made on Sanibel Island near Ft. Meyers, Florida to evaluate the capacity of lab-reared sterile males to compete with lab-reared normal males in mating released females. Because livestock were not on the island it was assumed that native screwworm flies would be scarce and not produce sufficient egg masses for evaluation. However, native screwworms were found to be as numerous as on the mainland, and to infest feral cats, opossums, and rabbits. This experiment showed that lab-reared flies performed well in nature, since a high ratio of sterile to fertile egg masses were collected from the wounds of sentinel animals. Indeed during the following winter, 1952-1953, when only sterile males were released at the rate of 100 per square mile, egg mass sterility temporarily reached 100% within the first 8 weeks of releases. However during the 12th week a fertile egg mass was found. Since Sanibel is only two miles from the mainland - a fraction of the parasite's flight range - we realized that eradication could not be demonstrated in this experiment because of migration across the channel between island and peninsula.

Clearly the feasibility of using sterile males to achieve eradication would have to be evaluated on a fully isolated island small enough to accommodate an experiment on a very limited budget. We believed that these requirements were met by Vieques, nine miles from Puerto Rico, but we were prevented from working there by the danger posed by use of half the island as a bombing range by the U.S. Navy. Fortuitously, B. A. Bitter, focused our attention on Curacao, Netherlands Antilles, forty miles north of Venezuela, South America. Bitter, an agricultural officer on Curacao, wrote to the USDA Entomology Research Division for recommendations on protecting dairy and grazing animals from the screwworm. I was dispatched to this island in July, 1953, to investigate its suitability for our test. Indeed, it had a serious screwworm problem dating back at least ninety years. The island was populated with about 25,000 goats and 5,000 sheep, 300 deer and numerous rabbits. Cattle and horses were present but were not considered significant screwworm hosts because of close surveillance and care by the owners. Because of mortality caused by the screwworm, many of the nanny goats had only one kid or none at all.

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On March 17, 1953, eight months after my survey, the way was finally cleared to begin the eradication test (Baumhover et al, 1955). Egg mass data were collected from screwworm infested goats maintained in ten pens throughout the entire island (additional pens were established later). During the first two weeks prior to the release of flies, all 288 egg masses collected were 100% fertile showing that unmated females did not oviposit and that our egg collection and incubation techniques were adequate. During the release of 200 irradiated flies of both sexes (see Note 1) per square mile per week for six weeks, egg masses collections increased from 121 in the first week to 277 during the sixth week. However on average only 15% of these egg masses were sterile. Obviously, the rate of 200 sterile flies per mile per week was insufficient to suppress the natural population. Therefore we compared two rates of release. On half the island we released 200 per square mile, and on the other half we released 800 per square mile. During the 3rd week of this test the higher rate resulted in 53% sterility, and the lower rate induced only 28% sterility. Therefore, beginning August 9, 1954, the entire island was treated with 800 sterile flies per square mile per week, although some deviations occurred because of fluctuating supply of sterile flies from the rearing facility at Orlando, Florida. During the first four weeks when egg masses averaged only 4.6 per pen, sterility increased from 69% to 79%, and by seven weeks sterility had reached 100%. No further egg masses were collected except for single, small sterile masses during the thirteenth and fourteenth weeks, respectively (Table 1).

These remarkable results were in close agreement with projections made with Knipling's model (1959). Eradication was achieved by increasing the release rate when the native screwworm population was in a period of natural decline.

Releases were continued through the 22nd week, when the test was successfully terminated. Through the news media, radio, and print, we requested livestock owners to report any larval infestations. Nine cases were investigated from mid-October to mid-December. All turned out to be *C. macellaria* the secondary screwworm fly, a scavenger of minor importance.

No further screwworms were seen on Curacao until 1971, seventeen years after eradication. We had outlined procedures for preventing re-infestation, but in spite of this the screwworm likely was reintroduced by infested livestock shipped from South America to be slaughtered at the abattoir on Curacao. Screwworms were again eradicated by October 25, 1977. This was accomplished by first using SWASS, a combination of a lure and insecticide. Its application for ten weeks suppressed the population by 65% - 85%. Thereupon eradication was easily achieved through the release of sterile males (Coppedge et al, 1978).

In 1953 sterile flies were released from a single engine training plane of World War II vintage. Initially, pilots of the Royal Dutch Airline, KLM, agreed to fly for us when not flying for KLM, but surprisingly some became airsick and others found their wives had better things in mind for them than dispersing screwworms on their days off. Fortunately I was able to enlist the services of Peter Mijs, an adventurous former pilot for the British Royal Air Force. He was ready on a moment's notice, but I had to agree to detour from the flight lanes to photograph incoming oil tankers so his partner could later board the ships to sell photos to the crew.

The old Texas strain was used on Curacao because the overworked crew at Orlando, Florida (Jack Graham, Don Hopkins, and Frank Dudley) did not have time to colonize a strain from Curacao.

Part of the difficulty in mass rearing arose from the failure to recognize that the first third of the flies to emerge are predominantly females and the last third are predominantly males. Since the early part of each weekly batch was irradiated and sent to Curacao the latest pupae were reserved for egg production. As a result the colony cages contained a high proportion of males. Males are highly aggressive sexually, so that when males outnumber females in a cage, the females die prematurely as a result of incessant sexual harassment. Under such circumstances egg production is reduced greatly (Baumhover, 1965).

Interestingly, Bushland was afraid we would eradicate the screwworm from Curacao before we gained detailed scientific information about population dynamics and other factors contributing to the success or failure of the sterile insect technique. On the other hand Knipling and Lindquist were confident that the technique was scientifically valid, but they were afraid we might fail because of operational difficulties. I felt we had a least a 50-50 chance of success.

When sterility of egg mass collections reached 100%, and later when collections decreased toward zero egg masses, Wes New and I experienced great suspense each evening as we tabulated the egg mass data. I wired the results daily to Lindquist who - along with Knipling - eagerly awaited the report.

The last two small sterile egg masses were collected after four weeks of zero collections. Probably these were second or third ovipositions by long-lived screwworm females. I was intrigued. Were these really screwworm eggs or the eggs from a rare species overshadowed by the screwworm? However, I verified that these were screwworms, since several of eggs in each mass had developed to the spined stage, characteristic of the sterilizing dosage delivered to our released males.

When eradication seemed imminent, I requested the local authorities to build a security pen completely enclosed with fly proof screen. Goats to be used as sentinel animals were infested with screwworms in this enclosure and held for three or four days. Infested wounds emit an odor produced by bacterial action which makes these wounds far more attractive to screwworms than uninfested wounds. Before the goats were removed from this secure compound, all larvae were removed from the wounds and killed with benzol. Subsequently these wounded goats were transported to the ten or more pens used to collect egg mass data. Fortunately, we never lost a goat through escape or theft, since fertile flies produced from the wounds of lost infested goats could seriously prolong the eradication program.

To increase our surveillance during the final weeks of the test we established additional pens in the lower southern portion of the island. Although a few sterile masses were collected during the first two weeks, the number quickly dropped to zero.

We are deeply indebted to the Curacao Administration, not only for allowing us to conduct the experiment but for assisting in carrying it out. Bitter was assigned to us full time and helped us immeasurably by procuring goats, securing the cooperation of land owners, solving problems as they arose, and assisting in routine fly releases and egg mass collections. KLM, the Royal Dutch Airlines gave priority to our fly shipments, which always arrived on time, even during the Christmas Holiday rush. The local government also furnished a caretaker who fed and watered our goats.

FLORIDA 2000 SQUARE MILE TEST

The success on Curacao induced the Florida Livestock Board to insist that the USDA draft a proposal for a Florida and Southeastern US Eradication Program. The proposed program would require a two year all-out effort on an enormous scale requiring the weekly production, irradiation and release of ca. 50 million sterile flies throughout 50,000 square miles. By contrast the Curacao program had involved only 170 square miles - not even 1 percent as large as required to cope with the parasite in the southeastern US - and had required less than 200,000 flies weekly.

Therefore an intermediate step was taken to test the sterile insect technique in a 2000 mi^2 area southeast of Orlando, Florida, bordering on the Atlantic Coast (Baumhover, 1958; Baumhover et al, 1959; Graham & Dudley, 1959). This was a cooperative effort of the Florida Livestock Board, USDA Animal Disease Eradication Division, and the USDA Entomology Research Division.

Because of the foul odors associated with larval rearing, a temporary rearing facility was constructed near Bithlo, an uninhabited area 20 miles east of Orlando, Florida. Several carloads of discarded temporary building sections were sent from Beltsville, MD and used by the ARS research team to construct a rearing facility. Since I had tinkered with radios and knew a little about electricity, I was appointed chief electrician. It was disconcerting to me and to other professional scientists to be removed from exciting on-going research projects, and required to work as laborers in construction. However - because adequate funds were rarely available - this was standard practice during the early years of research, development and implementation of screwworm sterile insect technique programs. Only after the successful eradication of the screwworm from Florida and the Southeast United States were adequate funds (ca. $500,000) appropriated annually for research to support the program in Texas, the Southwest U.S., and Northern Mexico.

Beginning May 2, 1957, one thousand flies per square mile per week (2 million) were released against a dense wild population which was infesting 80 to 100% of new born calves (Meadows, 1985). In spite of the severity of this screwworm outbreak , the number of egg masses in the release area declined from a high of 575 per week to only 17 the 16th week ending August 24, 1957, and egg mass sterility had risen to ca. 70% sterility by August 10 (Table 2). There was also a decline in egg masses in check pens south and west of the release zone, but collected egg masses remained numerous in the north.

Since the test area was not isolated, eradication could not be achieved. Nevertheless, since trends in the egg mass collections mimicked those on Curacao, the test was considered successful and it convinced livestock owners, various - but not all - government officials, and Florida legislators that eradication in Florida was feasible. Indeed Knipling (1985) stated if egg mass sterility under these circumstances had reached only 50%, he would have deemed the test to be a success.

ERADICATION IN FLORIDA AND SOUTHEASTERN UNITED STATES

Prior to 1933 the dreaded screwworm fly was not present in Florida, but when introduced with infested cattle from the drought-stricken Southwest into southern Georgia, it spread southward to overwinter in Florida. Moreover, within three years the parasite had infested the entire state. Losses were catastrophic until ranchers were given assistance by the USDA (Bruce and Sheely, 1944). An estimated 75,000 screwworm cases occurred in south Georgia during 1933, and by the end of 1934 an estimated 1,300,000 cases had occurred in Florida. Control programs sponsored by the State and the USDA reduced the annual cases to only 48,737 during 1936, and animal mortality of 12% during 1934 was reduced to only 0.71%. This type of control is essential to screwworm eradication by means of the sterile insect technique when conditions are ideal for an increase in the native population. Indeed this fact was demonstrated unequivocally in attempting to eradicate the persistent infestation in Broward and adjoining counties.

Florida livestock owners were particularly anxious to be rid of this intruder. However, the official USDA policy was that in spite of the success of 2000 mi^2 test, more research was needed. Consequently, the print media criticized the USDA "for dragging its feet". In a conference with Governor Collins of Florida, Knipling told him that two years of additional research would result in $2 million a year in savings. Collins replied, "why wait two years to save $2 million when losses are $ 10 million per year?" Indeed, these losses were estimated at $20 million by some ranchers and at $40 million by Knipling (1959). Thus Governor Collins astute reckoning made a deep impression on Knipling's philosophy regarding wide area insect control. Florida livestock owners, under the leadership of Okeechobee rancher, J. O. Pierce, soon convinced their legislature to appropriate $3 million as their share of a proposed $6 million program.

In September, 1957, after the successful conclusion of the 2000 mi^2 test about thirty individuals interested in the program met to design a mass rearing facility. Each time an additional, prominent participant entered the room the plan changed dramatically. However, in the end the final design was left to the genius of USDA engineer, C.N. Husman (Baumhover et al, 1966). Facilities at a World War II airbase, 7 miles east of Sebring had been selected as the site for rearing. Husman consulted frequently with us to determine optimum holding and handling conditions for the reared insects. Previously Husman had worked many years supplying equipment and facilities for entomological research. Frequently, we informally urged Husman to enlarge the dimensions of the requested facilities. As a result, he surreptitiously, but wisely, increased production capability by 50%. Indeed Husman was right in taking this action. After the program got underway as many as 80 million flies were produced weekly to cover 85,000 square miles during peak activity, when widely scattered cases required releases as far north as Montgomery Co., Alabama.

The operational program was initiated in an unexpected manner. However, luck was with us. The coldest winter ever recorded occurred in 1957-1958, killing screwworms southward to a line running from Tampa to Vero Beach, Florida. To take advantage of this break in the weather, USDA officials in December, 1957, decided to expand the research facilities at Bithlo to produce up to 13 million sterilized flies per week (Bushland, 1960). The intention was to use these sterile flies to prevent the reinfestation of the northern half of Florida and Georgia.

From January 18 to April 1, 1958, weekly production averaged only three million sterile flies weekly. These were released primarily in a band across the peninsula between Gainesville and Orlando at the 200 per square mile per week rate. However beginning April 1, 1958, when production had been increased to 14 million sterile flies per week, they were released at this rate across the northern half of Florida, and north to Savannah, Georgia, to combat scattered outbreaks above the overwintering line. Also some were released as far south as Miami.

Unfortunately, quarantine lines in Florida and along the Mississippi River had not been established in time to prevent shipment of infested animals into the screwworm free areas from the Southwest or from Southern Florida. It is conceivable that with adequate quarantines that flies from the Bithlo facility alone would have eradicated screwworms from the much reduced overwintering zone. Thus the large expensive plant at Sebring may not have been needed.

How would one have explained this to the administrators and the legislators who approved the $6 million dollar program? Simple: coldest winter ever recorded. Only 865 screwworm cases were confirmed in Florida from April 1, 1958 to February 19, 1959 (Table 3). Of this number only 31 occurred more than 50 miles above the overwintering line (Baumhover, 1966). However, there were 1901 cases reported but not confirmed of which 1711 (90%) were probably screwworms as found by Knipling & Rainwater (1937). Thus, the total number of cases probably was ca. 2575, or 0.08% of a possible 3 million cases if an eradication program had not been in effect. In less than one year, April 1, 1958 to February 19, 1959, screwworms were no longer detected in the entire Southeast.

Except for Broward County and the adjacent counties of Palm Beach and Miami-Dade, screwworms were only a minor problem throughout the remainder of the southern half of Florida during the entire program. Only 19 confirmed and 16 reported cases were recorded in these counties from January 1, 1958 through August, 1958 (35 weeks) for a weekly average of 1.0. However, during September, 1958 the average increased to 4.75 (Table 4) and peaked at 33.0 between mid December to mid January, 1959. The percent-infested wounds peaked at 5.86% during this same period. Finally, by February 19, 1959 the last infestation was recorded as a fertile egg mass (40 eggs) taken from a 1 day-old calf. This does not include a spurious case recorded June 17, 1959, and discussed below. An additional 23 sterile egg masses were collected up to March 13, 1959: 4 of these contained 6 eggs or less, and 2 had malformed eggs, indicating they were oviposited by released females. Similar data were obtained from adjacent Palm Beach and Miami-Dade counties but are summarized for brevity. Palm Beach had 32,434 wounds observed with only 35 cases (0.15%); Miami-Dade had only 3,321 wounds with 30 cases (0.90%). Even though egg mass sterility ranged from 74.5 to 76.3% from November 23, 1958 to January 17, 1959 (8 weeks), time for almost 3 generations, a substantial downturn in cases did not occur until mid February, 1959, when localized release rates had been increased from 400 to 10,600. In November 1959, eradication was declared, and the program was terminated.

PROBLEMS IN THE FLORIDA AND SOUTHEASTERN PROGRAM AND SOLUTIONS

A. Persistence of screwworms in Broward and adjacent Palm Beach and Miami-Dade Counties

1. The Problem:

a. Sharman (1960) attributed the screwworm outbreak in the Broward County area to "poor" quality flies. However, there is no evidence that the effectiveness of the sterile males had diminished. In fact it may have increased due to the reduced irradiation effects discussed below. Based on a review of the data available I am convinced that the primary reason for the outbreak was complacency of the ranchers. As shown above, screwworm cases averaged only 1.0 per week in Broward County, and less than this in Palm Beach and Miami-Dade from January 1, 1958 to August 31, 1959. Too many ranchers decided prematurely that eradication had been achieved, and they had abandoned the animal husbandry practices needed to avoid a population build up and serious losses.

b. Hundreds of new-born calves were not treated. Infested calves were not treated until after many of the larvae had left the wounds to pupate and later emerge as fertile flies. Calf navels accounted for 415 out of 491 (84.5%) collections made, including both egg masses and larvae from November 17, 1958 to March, 13, 1959. Over 36% of the wounds had mature 3rd instar larvae ready to drop out and pupate. One rancher had inherited an additional ranch and unsuccessfully attempted to maintain screwworm control without employing additional laborers. As a result he was one to two weeks late in treating his newborn calves. Another rancher, even though he had been advised by a livestock inspector that many of his herd were infested, delayed two weeks before rounding up his animals for treatment. A third rancher had no personnel to treat infested animals.

c. A wildlife refuge within the problem area contained feral hogs notoriously susceptible to screwworm infestation because of fighting and udder wounds created by suckling pigs. Feral hogs were also implicated in persistent screwworm populations in Hardee, Desoto, and Lee counties.

d. Korlansmear, a successor to EQ-335, proved to be ineffective in treating screwworms in wounds.

e. Release rates of 400 were not increased until late September, 1958. This was too late to prevent the build up of the native population.

f. Many fertile egg masses collected were small, indicating that long-lived females had mated to fertile males prior to substantial increases in the release rates.

g. In this southern portion of the state mild temperatures and rainfall were ideal for screwworm development and survival throughout the entire year.

h. We failed to realize that historically, screwworms had been most abundant in Broward County during each November, when most calves are born. Flytraps had been operated throughout the state prior to the eradication program, but the data did not reflect the potential for screwworm buildup in Broward County during November 1958.

i. The supervisor of airplane release operations decided not to disperse flies over metropolitan areas until it was apparent that screwworms were out of control.

j. Due primarily to the delay in establishing quarantine lines in northern Florida and along the Mississippi River, isolated screwworm infestations were found in Alabama and Georgia hundreds of miles from known infestations. As a result, 48 million sterile screwworms were released in Alabama and 66 million in Georgia. Had these outlying cases been prevented, these sterile flies could have been deployed in southern Florida to shorten the eradication effort.

2. The Solution:

a. Livestock inspectors were increased from three (one per county) to an average of six from October 4, 1958 to December 20, 1958, and then to an average of twelve through January 31, 1959 in an attempt to cover all the livestock owners in the infested area. Up to fifteen inspectors were active during the remainder of the campaign through mid-March, 1959.

b. Ground releases of flies were made on the most heavily infested premises to ensure an abundance of sterile males in the vicinity.

c. From November 18, 1958, until May 15, 1959, up to 193 liver-baited traps (Fig. 21) were operated in the infested area (4 per mi^2). During the first 13 days, 8 sampling traps caught an average of 6,037 released and 61 wild females for a ratio of 99: 1. From November 18, 1958 to December 14, 1958, 216 wild females were caught. During the same period only 73 infestations were found by livestock inspectors.

d. Egg mass collections were given priority since they provided the best measure of progress. As shown on Curacao, and in the 2000 square mile test in Florida, to achieve success egg mass sterility must increase as the number of egg masses collected decreases. From November 17, 1958 through January 23, 1959, (10 weeks) egg mass sterility averaged 76.5% in 230 masses collected but in the final week of this period 32 masses were collected, 9 more than the weekly average of 23 for this period. As Knipling's models show, this percentage of sterility is still not high enough to bring down the population when the potential for increase from one generation to the next is quite high, as it undoubtedly was in Broward and adjacent counties. Unfortunately, egg mass data after January 23, 1959 were of little value because of oviposition by sub-sterile females resulting from anoxia (Baumhover, 1963) in the irradiation canisters (see "D" below). However, only 2 fertile masses were found after this date. Although the scheduled dose rate of 8000r may have been reduced through anoxia to 4000r, this remained more than the 2500r required to sterilize males. As a result little if any hatch would be expected because of the preponderance of sterile males in the population. However according to LaChance (1963), if the released females had mated with fertile males, a substantial number of viable eggs would have been produced. In LaChance's two tests the females - which had been mated to fertile males and which had received 3500r - produced an average of 45.9 to 53.4 eggs each, of which 21.7 to 49.5% hatched.

e. All infested herds except two, reported by the livestock inspectors, were sprayed with CO-RAL, an effective insecticide with several weeks residual action (Fig. 22). One owner refused to round up his stock for treatment; and another had no one to round up her herd. Baby calves were treated only with insecticide "smears" because of their sensitivity to CO-RAL.

f. Heavy rains during January 1959 may have reduced emergence of pupae in soil in areas submerged for more than four or five days.

g. Special treatment ("hot spotting") was begun as early as June 6, 1958 in Osceola, Co. and later in Lee, Desoto, Hardee, Palm Beach, Broward and Dade counties. By October 1, 1958 we decided to move a mobile laboratory into counties with persistent infestations. However, by the time the lab was ready, all of the "hot spots" were free of the screwworm except Palm Beach, Broward and Miami-Dade. As a result, the mobile lab was set up November 17, 1958 in Broward County to develop the information given above.

Although we may never know how many of the above measures represented "overkill", in this "all out" assault the use of all possible weapons was justified since the entire program could not be terminated until the Broward County infestation had been eliminated. Needless to say the Herculean measures taken in this area caused much alarm to those contemplating an eradication program in

Southwestern United States. However, these results clearly indicate that a critical requirement of an effective eradication program is extensive cooperation from ranchers in promptly treating their susceptible and infested animals, particularly during periods of optimum weather when attractive wounds and navels are abundant. Without this cooperation, the cost of producing and releasing enough sterile males could be prohibitive.

B. Pupal Mortality

During the entire period of production at Sebring, pupal mortality averaged 25%. I found this to be caused by desiccation of prepupal and early pupal stages (Baumhover, 1963), which are highly susceptible to water loss until the prepupal membrane has formed. Larvae were reared on the second floor and dropped into huge funnels extending almost to the ground floor. They were collected in sand trays on a moving belt. Since the flow of larvae was erratic some trays were too heavily loaded and many of the young pupae remained on top of the sand, subjected to ambient temperature and humidity, until their transfer to a room controlled at 80°F and 85% relative humidity. Another disadvantage was the accumulation of spent medium in the funnels carried there by the larvae as they left the rearing media. This provided the traction needed by larvae to crawl up the funnel, and periodic air blasts were required to force them into the collection trays below. Surprisingly, the full-grown larvae were able to squeeze through the riveted seams of the aluminum funnels. These escapees would fall to the ground floor to create a fly escape hazard, since the lower floor was not fly proof.

Larval collection and protection from desiccation was greatly improved by installation of new collection system devised by Husman (Fig. 13) (Baumhover et al, 1966). It consisted of a water sluice onto which the larvae fell after leaving the rearing vats. I was not concerned about drowning the larvae since they were in the sluice only a few minutes and in my laboratory tests five days under water were required to produce 100% mortality. The sluice transported the larvae to a separator where they collected in measured quantities for placement in optimum numbers into pupation trays. Within minutes, the trays were transferred to a controlled room environment of 80°F. and 80% relative humidity. Under these conditions and improvements noted in "pupal separation" below, emergence increased to 95% or more.

C. Pupal Separation

At Sebring, the pupation trays were emptied every four hours onto a moving screen belt. Larvae crawled through the screen and were collected in sand trays to be returned to the pupation room. However, pupae remained on the screen and were collected at the end of the belt, and then poured into screen-bottomed trays to a depth of two inches. Pupae piled higher than two inches were subject to uneven development because of metabolic heat. Indeed some pupae piled more than three or four inches deep actually died from the resulting high temperatures. Large larvae and those partially immobilized as they entered the prepupal stage became stuck in the screen belt, and they were crushed by the roller. (This operation was improved in the Southwestern program by replacing the screen wire belt with a solid rubber, ribbed belt (Baumhover, ibid) (Fig. 15)). A bright light was mounted above the belt, and it caused the mobile larvae to crawl off. Subsequently the latter were returned to trays and transported back to the holding room. Another improvement was replacement of the sand with sawdust which could be burned when spent. When sand was used it had to be cleaned periodically with a steam generator, which caused delays occasionally when it had to be repaired. On such occasions, larvae were subjected to desiccation in the empty pupation trays or they were killed when hot sand was used.

D. Anoxia In Irradiation Canisters

During the heat of the Broward County campaign, pupae were irradiated at six days of age instead of five in an effort to improve the vigor of the released flies. As a result, the concentration of oxygen was reduced through increased metabolism. Consequently the effectiveness of irradiation was reduced, so that released females were able to oviposit large numbers of sterile eggs, (Baumhover, 1963). It was highly embarrassing to have to explain the rings of white eggs around animal wounds to ranchers. The answer was: "sterile screwworm eggs". To further exacerbate the difficulty one technician loaded pupae into many canisters far ahead of schedule. As a result of anoxia the scheduled dose of 8000r was reduced in effectiveness to that of 4000r. This was corrected by replacing solid portions of the canister walls and bottoms with screens (Fig. 17). Air could also be pumped through a drainage port connected to the bottom of the irradiation chamber to exit outside the irradiator. Needless to say, these egg masses from improperly irradiated females confounded the critically important egg mass. However, small egg masses from the released females could be recognized by their odd shapes, being blunt on the ends or being banana-shaped.

E. Fail-Safe Irradiation Procedure

At Sebring the irradiation attendant attached the radiation canister to a moving carrier. The carrier transferred the canister into and out of the irradiation chamber, and then returned it to the attendant who passed it to the packaging department. There was no mechanism to prevent the attendant from passing the canister to the packaging unit without first irradiating the pupae. Although there was no evidence that this ever occurred, it seemed prudent to forestall this possibility. This was done by changing the carrier to transfer the canister directly to packaging after being irradiated (Fig. 18). Once the canister left the attendant's hands it remained in a restricted area accessible only to the radiation supervisor (Baumhover et al, 1966).

For the Mexico program a new irradiator design by Husman was used. The irradiator was installed in the wall separating the radiation area from the packaging area. The only way the canister of pupae could be transferred to the packaging area was to pass it through the irradiation chamber. This unit contained $Cesium^{137}$ with a longer half-life allowing longer intervals before adjusting exposure time for decay and recharging the unit than required for the $Cobalt^{60}$ Units.

ERADICATION IN TEXAS, THE SOUTHWEST, AND MEXICO (see Note 2)

Initially, it was not considered feasible to attempt screwworm eradication in Texas and the other Southwestern states because of the 2000 mile long barrier required to keep screwworms from migrating back from Mexico into the Southwestern states (Bushland, 1952). However, when Texas ranchers learned of the success in the Southeast, a delegation of livestock owners headed by Dolph Briscoe, Jr. (later to be Governor of Texas) visited the Sebring plant to review the operation. They were told that the Southwest program would be more difficult but that it might be feasible. They were willing to take the gamble and returned to Texas to raise $3 million from ranchers who contributed $0.50 per cow and horse and $0.10 per sheep, goat and pig. The Texas Legislature appropriated $2.8 million and the Federal government appropriated $6 million to begin the program (Scruggs, 1975). A cold winter in 1961-62 killed screwworms deep into the normal overwintering zone in Texas, much like it had in Florida in 1957-58. A standby screwworm colony had been maintained in rearing facilities at Kerrville, Texas for use in the event that screwworms should reappear in the Southeast. Now this rearing operation was expanded to produce sterile flies needed to prevent flies from migrating northward from Mexico. The results of this huge undertaking were somewhat erratic (Bushland, 1985), but the program progressed aided by sterile fly production in a major rearing facility at Mission, TX. Thus by 1966 the entire United States was declared free of screwworms, even though occasional cases occurred due to the infiltration from Mexico. (For an early detailed history of the screwworm eradication program in the United States and Mexico, see Meyer and Simpson (1996), as well as Scruggs (1977) for in depth coverage of the Southwestern U.S. program.) It became obvious that because the 2000 mile barrier between Mexico and the United States was not only ineffective but costly, that screwworms had to be eradicated deep into Mexico to protect the United States.

In order to eradicate the screwworm in Mexico, an agreement was negotiated, which included a cost-sharing arrangement. Also the Mexico-USA Commission for Screwworm Eradication was established to manage the effort. The Mexican program began in 1976 with construction of a rearing plant at Tuxtla Gutierrez, Chiapas, Mexico. The Mission, Texas plant continued to operate along with the Chiapas plant until January, 1981 by when screwworms had been eliminated from the Northern states of Mexico. By 1987, the Mexican government declared the area north of the sterile-fly barrier at the Isthmus of Tehuantepec to be screwworm free (Meyer and Simpson, 1996). Moreover as a result of continuing effort, Mexico was officially declared free of screwworms in 1991, Belize and Guatemala in 1994, and El Salvador in 1995. In addition, Honduras, Nicaragua, Costa Rica and Panama are largely free of the parasite. The new barrier is being established at the narrow Darien Gap in the Isthmus of Panama.

During the screwworm eradication program in Puerto Rico completed in 1975, the western 1/4 of the island remained screwworm free for eighteen months even though the eastern 3/4 was infested. Apparently, the ideal conditions for screwworm survival reduced movement. If similar conditions exist in the Isthmus of Panama, we may be pleasantly surprised at the reduced cost of maintaining this barrier.

EDEN - LINCOLN REPORT

Following a screwworm outbreak in Texas, in 1972, when 95,625 screwworm cases were confirmed with many others not reported (Bushland, ibid) Congress ordered an investigation of the program by outside specialists. The study was conducted by Dr. Charles Lincoln, Entomologist, Department of Entomology, University of Arkansas and Dr. W.G. Eden, Chairman, Entomology and Nematology Department, University of Florida.

They stated that, "in our combined 78 years of professional work, we have not seen an area program of any kind that has the popular grower support of the Southwestern Eradication Program." They further stated, "we unhesitatingly recommend that the work of the Mexican-American Commission for Screwworm Eradication proceed on schedule." They rated individual years' results as "seven good, three fair, and one terrible, not a bad track record" (Eden and Lincoln, 1974). In a survey contracted by these authors in Florida, six prominent ranchers stated that return of the screwworm would "put them out of business". They related that screwworm infestations had required all their waking hours to reduce losses. All of these ranchers had up-graded their herds from "range cattle" to purebred stock after the screwworm had been eradicated.

SCREWWORM STRAINS

The scientific soundness of methods used in the process of establishing, adapting, evaluating and selecting screwworm strains to be mass reared irradiated and released has always been of great concern to screwworm program personnel, particularly when field results were below expectations. Attempts were made to colonize a Curacao strain for release on that island, however, due to a lack of resources and personnel this was not accomplished. Wild strains are difficult to colonize because of their refusal to mate or produce eggs under laboratory conditions. Nevertheless, larvae from eggs of wild flies adapt readily to the artificial medium. However, we rationalized that conditions for screwworm survival on Curacao were similar to Texas, and that the Texas strain could be expected to perform adequately on this island.

Indeed, as we have seen above, the old Texas strain used on Curacao was eminently successful in eradicating the native population when the latter was undergoing a natural seasonal decline. Nevertheless, we took a significant risk by not establishing a Curacao strain of screwworms for use in the event that the Texas strain had proved unsatisfactory.

For the Florida campaign we developed a local strain (FLA) and selected it for sexually active and long-lived males. C.C. Skipper, our able survey supervisor and liaison with local ranchers collected fully-grown larvae from infested cattle throughout Florida and in Southern Georgia. To obtain sufficient egg masses in the first generation we had to use infested goats to induce oviposition. To select a vigorous strain my assistant, Wes New, caged single males with 25 virgin females. Progeny from males impregnating the most females - ten or more - and living the longest were pooled for subsequent selection. By the 5th generation longevity had improved and successful matings per male (based on egg hatch) had increased from 5 to 17. George Spates and I later observed that individual males actually mated up to 72 times over a 7 day period when an abundance of virgin females was present. However after the 6th or 7th mating on a particular day they no longer were able to transfer viable sperm. Nevertheless on the following day, the males again transferred sperm during matings.

Our selection for long-lived sexually active FLA males was completed in time for use in the 2000 mi^2 test in Florida. This strain was also used during the entire Florida campaign and in the Southwest from April 1962 to December 1966 when it was replaced by the Mexico strain. This action was taken without field testing the performance of the FLA strain, and was decided merely on the assumption that after ten years the FLA strain may have deteriorated, and that it no longer was competitive with Southwestern U.S. and Mexican screwworms (Eden-Lincoln, ibid.). Eleven additional strain changes were made from November, 1971 to May, 1985, based on screwworm outbreaks or inadequate adaptation to mass rearing conditions. However, strain changes made after January, 1974 were based on field tests. In Mexico strain changes are made on a periodic "programmed basis" using field tests (Marroquin, 1985).

Several attempts were made to colonize a Puerto Rican strain of screwworms. These island flies were smaller in size and had a shorter life cycle than the mainland screwworms. On one of my trips to Puerto Rico I collected several egg masses and placed the hatched larvae on a rearing medium. Since I couldn't wait for pupae to form (a much more feasible method of transporting live insects) I carried them in a rearing container enclosed in a plastic bag to avoid escape of the fetid odors associated with rearing. However, whenever the plane landed I removed the package from the plane and opened it to provide air exchange. Although my specimens arrived at the Mission, Texas, plant in good condition, attempts to colonize them were unsuccessful. The eradication effort in Puerto Rico and surrounding islands, using sterile screwworms produced at the Mission, Texas plant, was hampered by a ten day shipment delay between radiation and release. Pupae were held at 60°F to prevent emergence, and this greatly reduced vigor of the flies. However, when the delay was reduced to only three days, eradication proceeded on schedule.

CRITICS

We were able to eradicate screwworms from Florida and the Southeast in less than a year, well before critics could marshal their forces against the program. This was not the case in Texas. In 1966 the entire United States was declared free of screwworms and it became a federal responsibility to maintain the barrier zone from the Gulf of Mexico to the Pacific. Thus the States most affected by the parasite did not have to cost-share the program. Since the program could not proceed deep into Mexico during the 9 years required to negotiate an agreement, the strategic character of the program changed from eradication to area-wide population management. However USDA Officials and State and Federal politicians continued to refer to this holding action as an eradication program. Therefore critics had a field day when screwworm outbreaks occurred in 1968 and 1972. Several critics branded the program a failure and recommended that it be abandoned. Most of the speculation revolved around incompatibility of the wild females with the released, sterile males. If this were the case, the appropriate counter measure would be to colonize, sterilize and release the wild strain. Graham (1985) lists six articles purporting to explain the reasons why the sterile male technique may not work, none of which proved to be valid.

Other Items Of Interest

A. Early in the Florida program a screwworm sample was received from a South Carolina veterinarian, prior to any collections from the overwintering area in Florida. This concerned us deeply until the sender admitted that he collected larvae of fly species other than the screwworm from a wound, but inadvertently he had interchanged this non-screwworm collection with a sample of screwworms.

B. After several months of negative screwworm reports in the Southeast, a livestock inspector in northern Florida reported a navel infestation in a new born calf. This induced the epitome of consternation for we had never seen larvae other than screwworms in an infested calf navel. However if confirmed this development would have gladdened the hearts of critics who predicted that the screwworm, if eradicated, would be replaced by another pest. I was flown to the area to investigate. As I approached the calf, I detected a sweet odor in contrast to the foul smell of a true screwworm infestation. To our great relief the navel area contained a neat pocket of a *Lucilia* species, behaving like screwworms, and rarely seen previously. Indeed, if the infestation had been that of the screwworm, it would have caused the extension of the expensive eradication program for additional months.

C. In late 1959, an inspector had reported the possible infestation of 20 steers in south Florida. They had been castrated with a knife, the preferred method in screwworm free areas, instead of the bloodless method using constricting "O" rings. At first glance the scrotal areas were swollen and bleeding, similar to wounds with screwworm infestations. Fortunately, no screwworms were found, and this was additional evidence that screwworms were scarce or non-existent.

D. I had the opportunity to solve a toxicity problem with the release cartons at Mission, Texas, site of the Southwestern screwworm plant. One of the investigators released flies from the cartons into a cage, removing the carton shortly after the flies had left. These flies lived normal life spans. I decided to conduct the same test leaving the cartons in the cage overnight. The following morning most of the flies were dead. Chemical tests detected a light residue of the widely used insecticide, Lindane, in the cardboard. Since that time, release cartons and partitions have been made only from virgin materials rather than recycled products.

E. On another occasion I was asked to head a team investigating an unusual number of screwworm cases near the Mission, Texas plant. Wild type screwworms had an interruption in the circle of spines on the 11th segment (Fletcher, 1966); for an unexplained reason the plant strain had complete banding. Since larval collections near the plant contained complete banding, I concluded that the screwworm infestations were originating from the plant. Although my conclusion was not readily accepted, later inspection of the fly colony room revealed cracks in the walls. Since the fly colony room was kept in the dark to prevent flies from congregating toward the brightest light source, the daylight visible through the cracks was highly attractive to flies in the room. Further evidence that flies were escaping was obtained when larvae from collections near the plant quickly adapted to plant rearing, whereas wild screwworms are usually colonized with much difficulty.

F. No screwworm infestations were found in Florida from February 19, 1959 to June 17, 1959. However, on June 18 a confirmed sample was received from a ranch within ten miles of the Sebring plant. The true origin of the specimens was never determined, however, one of the following possibilities could have occurred:

(i) A load of 100 Texas cattle transported by train had been delayed on a ranch near the screwworm plant at Sebring, Florida, several weeks before the infestation was reported. Screwworms may have escaped from infested animals.

(ii) Screwworms may have escaped from the plant, an ever present concern.

(iii) Sabotage may have been carried out by an employee hoping to extend his tenure in a well paying job by the unlikely opportunity to remove fertile screwworms from the plant or by preparing a bogus report accompanied by a sample of screwworm larvae.

(iv). Ranchers have been known to retain screwworm samples for later use to "test surveillance by program personnel" or to obtain insecticide treatment of the herd. This is tempting, since the CO-RAL spray used on screwworm infested herds also controls other insect pests and ticks.

(v) The rancher may have inadvertently delayed submission of the sample.

SUMMARY

Eradication of the screwworm from Curacao, followed by a successful 2000 mi^2 test in Florida led to the eradication of the parasite from the entire Southeast. This successful program served as a pilot test for the Southwest with improvements in mass rearing, irradiation and understanding of factors in problem areas. At the present time screwworms have been eradicated from more than 90% of the previously infested areas in North America. The cost benefit ratio in Texas has been calculated as high as 1:113. Since 1958 the savings in North America are undoubtedly in the billions of dollars (Knipling, 1997), and will continue at a half billion annually so long as screwworms are prevented from re-infesting the screwworm-free areas. Eradication from the Southwest protects the Southeast; eradication from Mexico protects the Southwest and the barrier in Panama will protect all of Central and North America.

I was very fortunate to have played an official role in screwworm eradication from 1951 through 1965, when Dr. Knipling asked me to head the USDA Tobacco Insects Investigations. However, I remained in close touch with the program and attended many of the quarterly staff meetings as well as emergency sessions until my retirement, February 4, 1984.

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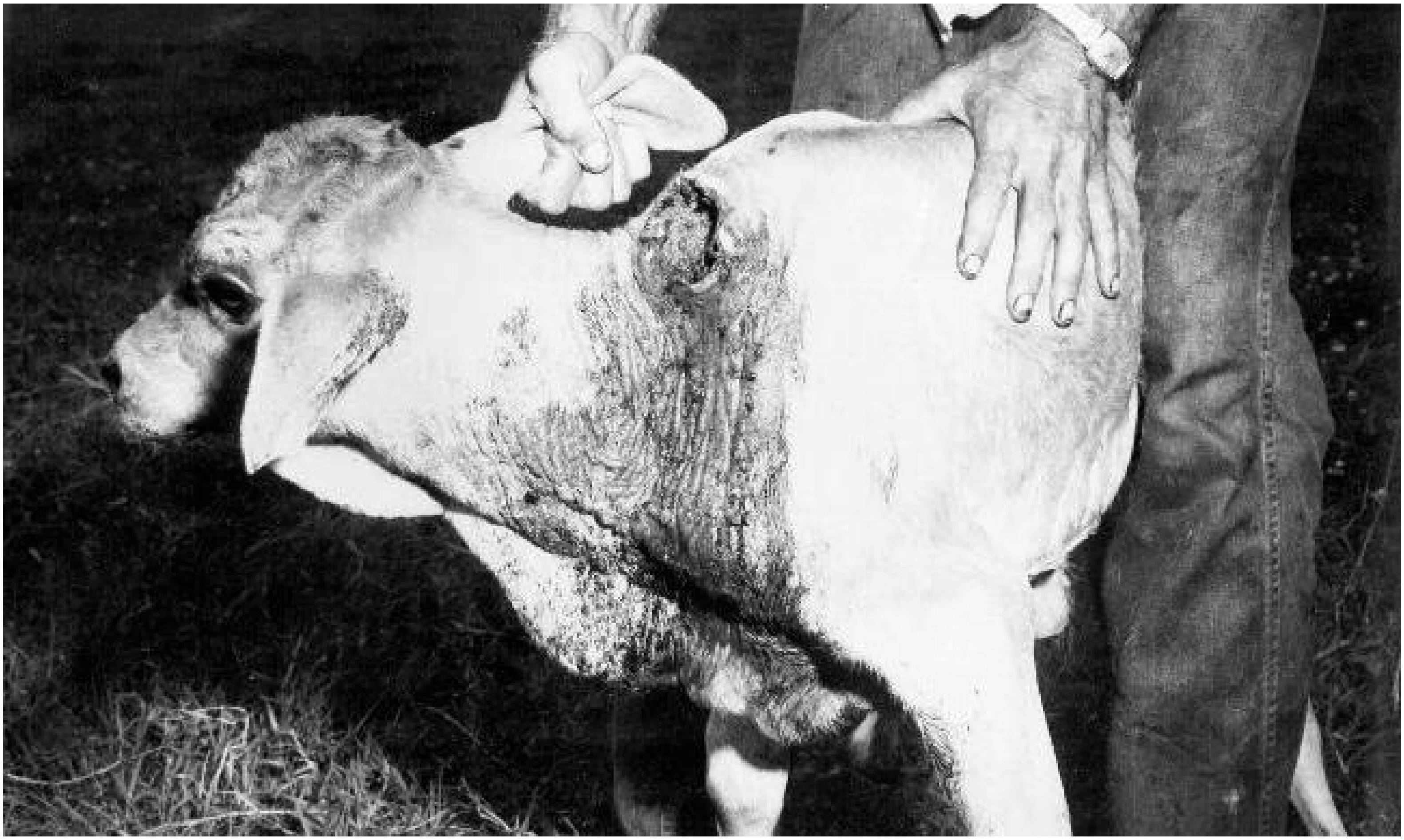

Fig. 1. Infested Brahma calf. Note the closely packed larvae in the wound (ca. 1000) and the small white egg masses on the dry edge. If not treated thousands more larvae would develop and result in the death of the calf within a week. (Author)

Fig. 2. Screwworm adult flies. Male on left; female on right. Adults are about 3x the size of the common housefly. (Author)

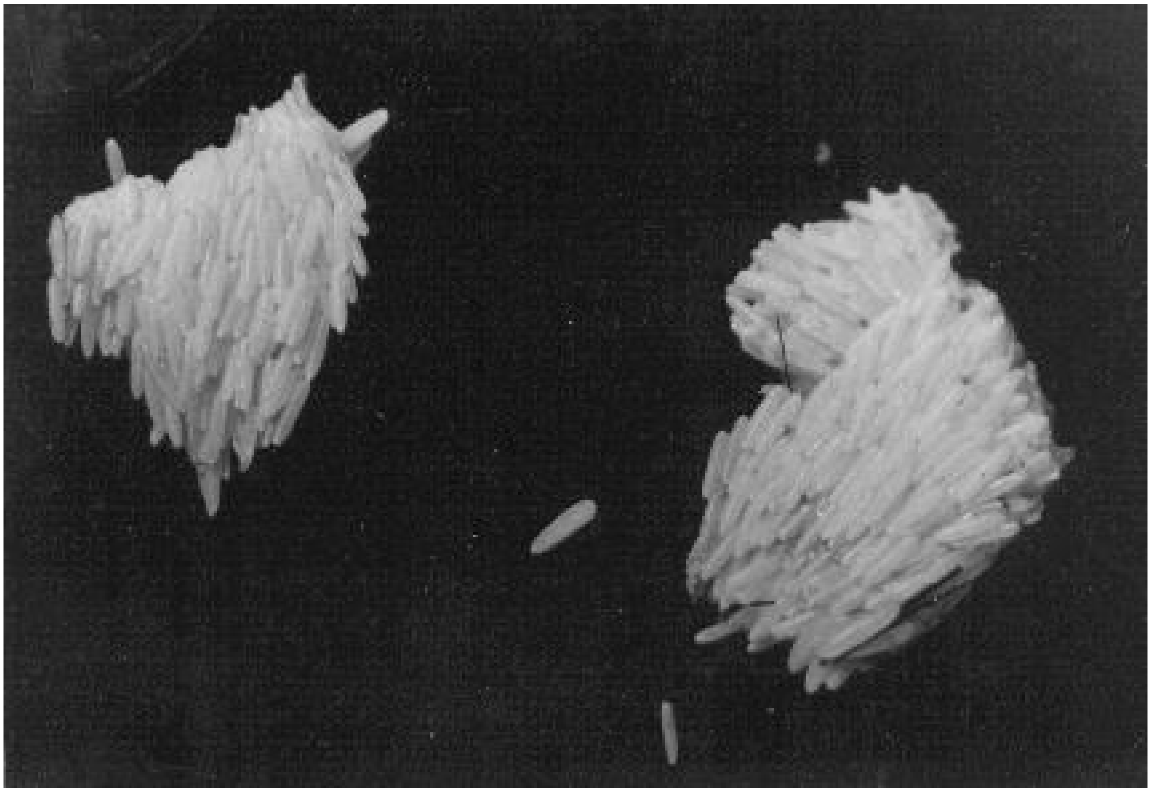

Fig. 3. Screwworm egg masses. Females lay up to 300 eggs per mass, firmly glued together on the dry edge of a wound. Eggs hatch in 12 to 24 hours. (Author)

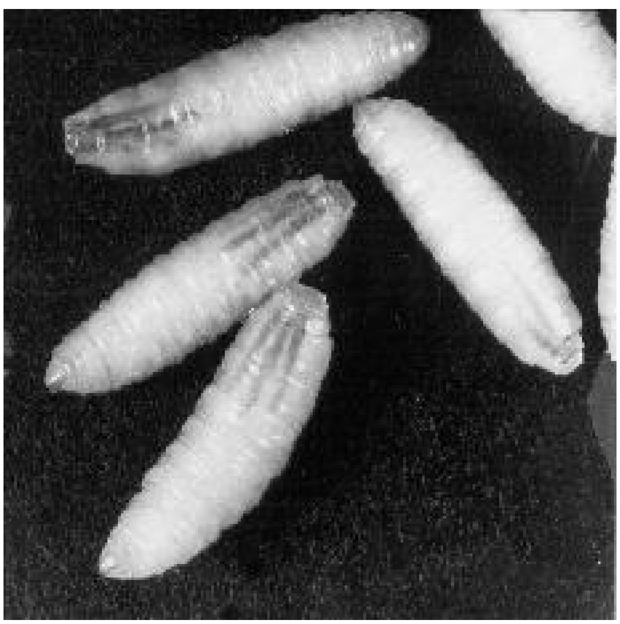

Fig. 4. Full-grown 3rd instar screwworm larvae, 1/2 inch long, weigh 90 to 120 mg. when reared in a live host, but weigh considerably less when reared on artificial diets . Dark trachea on posterior distinguish screwworm larvae from other blow flies. Larvae feed for 6 to 7 days before leaving wound or artificial diet to pupate in soil or medium. (Author)

Fig. 5. Screwworm pupae. Adults emerge in 7 days and oviposit at 6 to 7 days completing the life cycle in 21 days at an average temperature of 80°F. (Author)

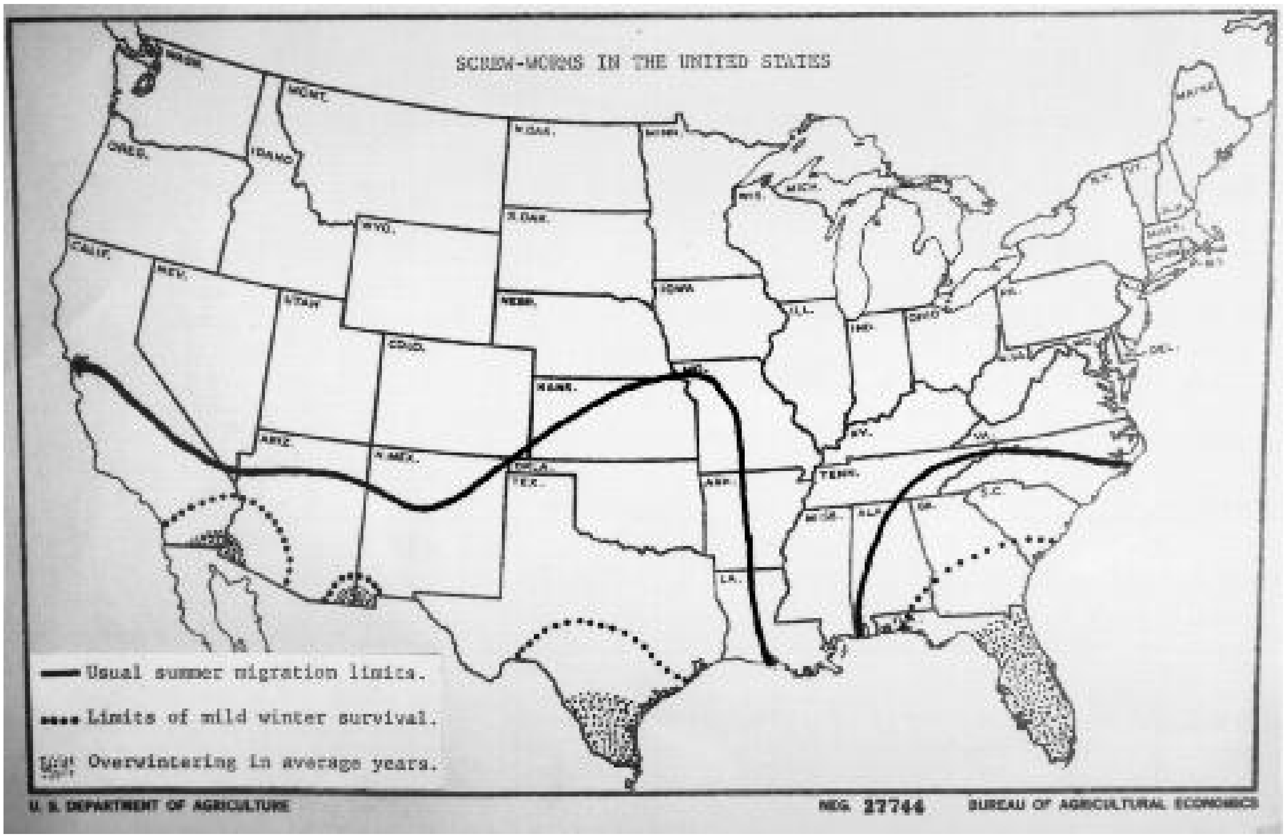

Fig. 6. Screwworm distribution in the United States prior to eradication, based on surveys from 1933 through 1957. (USDA)

Fig. 7. U.S. Air Force hangar near Sebring, Florida, converted to a screwworm fly rearing factory. (Author)

Fig. 8. Fly colony cage. Six liters of pupae were placed in this cage to produce approximately 50,000 adults. Four million or more eggs were produced per cage. Paper streamers were placed in the cage to provide resting surface for the flies. Food consisted of a honey-meat mixture, honey alone, and water (USDA).

Fig. 9. Fly colony holding room. (USDA)

Fig. 10. Grid removed from oviposition tray for removal of screwworm eggs. Eggs were weighed into 6-gm lots to provide 120,000 eggs for each starting tray. (USDA)

Fig. 11. Transfer of hatched screwworm larvae from Petri dish to starting tray. Larval medium consisted of lean ground meat, bovine plasma, water, and formalin. The starting chamber was maintained near 100°F and 95% RH. (USDA)

Fig. 12. Third instar larvae in rearing medium. (Author)

Fig. 13. Screwworm rearing vats. After 30 hours in the starting chamber the larvae were transferred to vats on the main floor. Diet was similar to the starting medium except that whole bovine blood was substituted for plasma. After 4 days larvae reached the size shown, migrated from the vat, and were directed to the water conveyor beneath the grate. (USDA)

Fig. 14. Sawdust separator. Larvae were collected at the larva-water separator (not shown) and placed in pupation trays containing sawdust; 16 hours later the sawdust was removed from the mixture of larvae and pupae to permit separation of the life stages. (USDA)

Fig. 15. Larva-pupa separator. The mixture of larvae and pupae was transported to a slowly moving endless belt. The negatively phototropic larvae crawled to the sides and dropped into containers for recycling in the pupation chamber. Pupae, remaining on the belt, were collected at the opposite end for storage. (USDA)

Fig. 16. Irradiation canister being loaded with 2 liters of pupae (18,000). Pupae received 8000r ± 10% at 5 1/2 days of age. (USDA)

Fig. 17. Positioning irradiation canister on carrier, which inserted it into the irradiation chamber and automatically removed it at the scheduled time for transfer to the packaging area. (USDA)

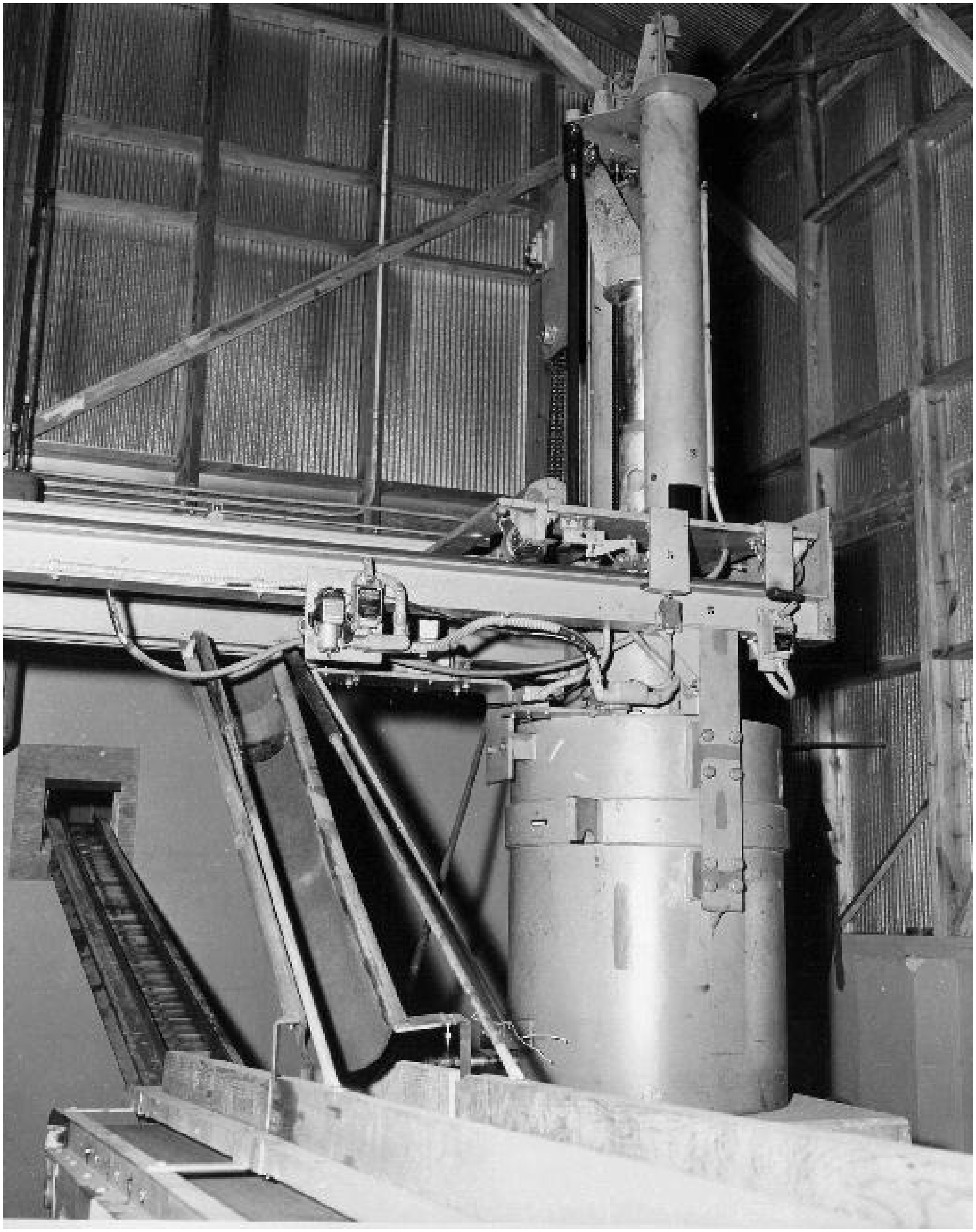

Fig 18. Cobalt[60] irradiation unit in restricted area accessible only to the radiation supervisor. Screened canisters containing screwworm pupae were attached to the carriage at the operator's position (Fig. 17) and were automatically inserted into the radiation field, removed, and dropped onto the packaging room conveyor in the lower left hand corner. (USDA)

Fig. 19. Packaging line. Operator on stool emptied the irradiated screwworm pupae into an automatic filler which dispensed the pupae into the release cartons. Cartons were formed and closed mechanically at the rate of 50 per minute. (USDA)

Fig. 20. Release airplane flew at 1000 ft. above the terrain usually in flight paths 2 miles apart. Small dark objects at lower right are the release carton and the partitions inserted to provide resting surface for the flies. (Author)

Note 1.

During the early field tests release rates were listed as males only even though both sexes were released. However, in this paper the rates include both sexes unless otherwise specified.

Table 1
Egg Mass Records During Release Of
Approximately 800 Sterile Screwworms Per Square Mile Per Week
On Curacao, Netherlands Antilles

Total Egg Masses From Eleven Goat Pens

Week No.	Date (1954)	Number Fertile	Number Sterile	Number Total	% Sterile
1	Aug. 9 - 15	15	34	49	69
2	16 - 22	17	38	55	69
3	23 - 29	17	36	53	68
4	Aug. 30 - Sept 5	10	37	47	79
5	Sept. 6 - 12	7	42	49	89
6	13 - 19	3	23	26	88
7	20 - 26	0	10	10	100
8	Sept. 27 - Oct. 3	0	12	12	100
9	Oct. 4 - 10	0	0	0	-
10	11-17	0	0	0	-
11	18-24	0	0	0	-
12	25-31	0	0	0	-
13	Nov. 1 - 7	0	1	1	100
14	8 - 14	0	1	1	100
15	15 - 21	0	0	0	-
16	22-28 *	0	0	0	-

*Survey continued through week 22 (January 3 - 6, 1955) with no further egg masses or infestations found.

TABLE 2
EGG MASS RECORDS DURING RELEASE OF STERILE SCREWWORMS IN A 2000 MI^2 TEST AREA IN EAST-CENTRAL FLORIDA,1957.

Egg masses were collected from wounded sentinel animals confined in pens. Pens were organized into groups.

	RELEASE AREA				CHECK AREAS					
	GROUP II		GROUP 111		GROUP I (NORTH)		GROUP IV (SOUTH)		GROUP V (WEST)	
DATE	TOTAL NUMBER	PER CENT STERILE	TOTAL NUMBER	PER CENT STERILE	TOTAL NUMBER	PER CENT STERILE	TOTAL NUMBER	PER CENT STERILE	TOTAL NUMBER	PER CENT STERILE
May 2-4	75	0	12	0	11	0	-	-	-	_
5-11	214	4.7	39	7.7	61	1.6	61	0	32	0
12-18	283	5.3	11	0	92	4.3	72	0	50	8
19-25	151	9.9	47	23.4	146	1.4	100	0.1	44	9.9
26-June 1	119	4.2	188	23.9	184	5.4	94	1.1	43	2.3
June 2-8	182	10	376	19.1	140	0.7	102	2.9	45	2.2
9-15	160	8.7	415	25	133	1.5	96	2.1	56	0
16-22	186	25.3	333	40	200	0	78	0	30	0
23-29	104	25	244	42.1	185	1.6	36	5.6	24	4.2
30-July 6	88	27.3	194	40.7	111	3.6	18	0	18	0
July 7-13	70	40	103	44.7	121	0.8	13	0	6	0
14-20	56	62.5	97	78.3	94	3.2	6	0	8	50
21-27	33	69.7	65	69.2	154	11	9	0	4	0
28-Aug.3	5	80	15	73.3	133	0	3	0	3	0
Aug. 4-10	11	72.7	14	64.3	112	5.4	10	0	0	-
11-17a	12	58.3	38	60.5	125	4.8	20	0	1	0
18-24	0	-	17	52.9	129	5.4	4	50	0	-
25-30	4	25	14	35.7	99	1	14	14.3	0	-

[a]. Final release

Table 3
Total Number Of Confirmed Screwworm Cases In Florida And Those 50 Miles Or More Above The Overwintering Line
1958 –1959

Date	Counties	Number Total		Above Overwintering Line
1958				
Jan. - March	10	15		2
April - June	35	328		25
July- Sept.	18	131		1
Oct. - Dec.	11	277		1
1959				
Jan. - March	5	113		1
April - June	1	1	*	1
July - Sept.	0	0		0
Oct. - Dec.	0	0		0
		865		31

*Spurious case, origin not determined (see text).

TABLE 4
BROWARD CO.
WEEKLY AVERAGES OF WOUNDS OBSERVED,
SCREWWORM CASES, EGG MASSES COLLECTED,
INSPECTORS PRESENT AND RELEASE RATES
DURING THE SCREWWORM OUTBREAK 8/30/58 TO 2/28/59.

	WEEKLY AVERAGES			EGG MASSES				
DATES	WOUNDS	CASES	% INFESTED[b]	TOTAL	STERILE	% STERILE	INSPECTORS[d]	RELEASE RATES
8/30 - 9/27/58	689	4.75	0.69	-	-	-	1.0	400
9/28 - 10/25	635	8.0	1.26	-	-	-	1.0	1150
10/26 - 11 /22	922	20.5	2.22	-	-	-	1.0	1875
11 /23 - 12/20	1023	22.0	2.15	55	41	74.5	5.5	3600
12/21 - 1/17/59	563	33.0	5.86	131	100	76.3	5.2	4300
1/18 - 2/14	384	9.75	2.54	44 [c]	39	88.6	9.2	10600
2/15 - 2/28	442	0.5	0.113	1 [e]	0	0	4.0	10600
TOTAL	17,756	384	2.2					

[a] All entries cover 4 weeks except final period covers 2.
[b] Includes both confirmed and reported cases and fertile egg masses from unifested wounds.
[c] Includes collections only from 1/18 - 26/59 when released females began ovipositing due to anoxia. (See "D. Anoxia In Irradiation Canisters").
[d] Includes only inspectors collecting samples. As many as 15 were present during the final phases to increase surveillance and to spray infested herds.
[e] Last evidence of native screwworm activity, a fertile egg mass from the navel of a one day-old calf.

Fig. 21. C.C. Skipper, Survey Specialist, inspecting a liver-baited trap that attracts female screwworm flies along with many other flies including the economically unimportant *C. macellaria*. The trap was used to study movement of the screwworm, ratios of released flies to native flies, and as an additional measure of control, as used in Broward County. (Author)

Fig. 22. Typical Florida ranch scene. During screwworm outbreaks ranchers spent all their waking hours inspecting and treating their livestock, but still suffered losses particularly in heavily wooded and brushy areas where infested animals tend to hide.

Note 2.

For a detailed history of the screwworm eradication program in the entire United States and Mexico, see Meyer and Simpson, 1966. Also see Scruggs, C.G. 1977, for an in-depth coverage of the Texas (Southwestern) program.

Note 3.

Adapted from:

Snow, J. Wendell, A.J. Siebenaler & F.G. Newell. Annotated Bibliography of the Screwworm. *Cochliomyia hominivorax* (Coquerel) U.S. Department of Agriculture, Agricultural Reviews and Manuals. ARM-S- 14/January 1981. 32 pp. 621 references.