A Personal Account of Creating the Sterile Insect Technique to Eradicate the Screwworm From Curacao, Florida and the Southeastern United States

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A PERSONAL ACCOUNT OF DEVELOPING THE STERILE INSECT TECHNIQUE TO ERADICATE THE SCREWWORM FROM CURACAO, FLORIDA AND THE SOUTHEASTERN UNITED STATES

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ABSTRACT

The history is recounted of developing the sterile insect technique to eradicate the screwworm, *Cochliomyia hominivorax* (Coquerel)**,** from the Caribbean island of Curacao, Florida and the southeastern U.S. Observations of screwworm biology and challenges faced in conducting these eradication projects are described by the author who worked on all aspects of the research and field operations. Eradication was first demonstrated on Curacao, essentially a 170 mi^2 outdoor laboratory. The population dynamics of the wild screwworm was determined and overflooding ratios and dispersal patterns essential for population suppression were defined. Eradication was achieved with minimal resources by attacking the pest during the time of year when it is least abundant. In Florida, eradication was greatly facilitated by an unusually cold winter that reduce the range and density of the target population. Eradication could not be attained easily by only suppressing the reproduction of adult screwworms. The larval population also had to be reduced to increase the ratio of sterile to wild males. It was essential to control the immature stages by diligent inspection and treatment of animal wounds. Leadership of the cattle producers was critical not only for securing program resources from the clientele, state legislatures and U.S. Congress, but also for gaining the cooperation of virtually all livestock owners. Additionally, leadership was required to acquire adequate research, extension and public information resources. Lessons learned from this work were corroborated repeatedly as the screwworm eradication program moved into the Southwest, Mexico and the Central America.

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

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.

Translation provided by author.

The screwworm, *Cochliomyia hominivorax* (Coquerel), is an obligatory parasite of living warm-blooded animals, including man. The female oviposits on any lacerated or bloody area potentially caused by fighting, barbed wire scratches, castration, dehorning, branding, or ticks, and on body openings with fetid odors. The tender navels of newborn animals are particularly attractive. Unless infested wounds are treated with an insecticide, flies will continue to oviposit on the host until it is nearly dead. The screwworm has a life cycle of about 21 days during periods of warm weather (Laake et al. 1936). Prior to eradication, its annual overwintering area in the U.S. varied with the severity of the winter. The average overwintering zone was 50,000 mi^2 in Florida and about 150,000 mi^2 in the southwest (Texas- 70,000; New Mexico-1,000; Arizona-35,000; and California-46,000) (Laake et al. 1936; Scruggs 1975; Meyer and Simpson 1996). It survived as far north as Oklahoma in the Southwest and South Carolina in the Southeast during mild winters. Fortunately, a severe winter in 1957-1958 eliminated screwworms above a line extending from Tampa to Vero Beach, Florida. This weather fortuitously enabled use of the sterile insect technique (SIT) to eradicate screwworms from Florida and the Southeast in about one year.

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SIT involves mass rearing harmful insects, sexually sterilizing them usually with gamma radiation after adult somatic cells have developed and releasing them so that sterile males will compete with wild males for mates. The radiation dosage must be sufficient to induce sexual sterility in both sexes. Wild females mated to sterile males oviposit normally and the embryos initiate development but die before hatching.

PRE-CURACAO

E. F. Knipling first conceptualized the use of SIT to suppress screwworm flies on an areawide basis in 1937 (Knipling 1955). He visualized the sustained release of large numbers of sexually sterile males into a wild population to eliminate reproduction and lead to eradication. His idea was not considered seriously at the time by his superiors in the U.S. Department of Agriculture (USDA), Bureau of Entomology and Plant Quarantine. However, the it remained firmly in his mind and was discussed repeatedly with his close colleagues, Drs. A.W. Lindquist and R. C. Bushland. During World War II, Knipling and Bushland worked on projects to protect the armed forces from arthropods and arthropod-borne diseases. After the war, as Knipling rose rapidly through the Bureau's ranks, he was able to secure limited funds to conduct research on his idea.

Bushland had already fulfilled one of the requirements of SIT by developing an artificial diet for rearing the screwworm (Melvin & Bushland 1936, 1940). The diet consisted of lean ground beef, blood, water and 0.2% formaldehyde to deter decomposition. Screwworms had been reared previously by infesting rabbits or baby calves, a very nasty and cruel procedure. Bushland evaluated various chemicals to induce sexual sterility but none was effective. However, H. J. Muller reported in 1950 that exposure of *Drosophila melanogaster* Meigen to high doses of x-rays induced dominant lethal mutations in the germ cells (Muller 1950). These mutations in the sperm of irradiated males, mate with untreated females, prevented the development of embryos and thereby caused sexual sterility. A. W. Lindquist read this popular article aimed at swaying public opinion against atmospheric tests of atomic bombs and showed it to Knipling. Knipling corresponded with Muller, who expressed confidence that ionizing radiation would induce sterility in the screwworm. With Knipling's encouragement, Bushland investigated the effects of x-rays on screwworm sexual behavior and reproduction (Bushland 1952). Subsequently, he and D E. Hopkins induced sterility in screwworms exposed as late pupae or adults to x-rays or gamma rays from Colbalt^{60} (Bushland & Hopkins 1951, 1953). They showed in laboratory cage tests that the capacity of sterile screwworm males to compete with untreated males in mating with untreated females was acceptable at dosages required to sterilize both males and females. Since the screwworm female mates only once, all egg masses oviposited by a wild female mated with a sterile male are non-viable.

To assist in evaluating the performance of irradiated sterile males in the field, I was reassigned from the USDA Grasshopper Control Division, to the USDA's Insects Affecting Man & Animals Laboratory at Kerrville, Texas and later to a sublaboratory at Orlando, Florida. Bushland had previously attempted to evaluate the field performance of irradiated screwworm males on the shoals of the Texas coast near Austwell. However, no egg masses were oviposited on wounded sentinel goats, apparently because the released flies were blown to the mainland by the strong prevailing winds. Subsequently, during the winter of 1951-1952, efforts were made to evaluate the competitiveness of sterile relative to lab-reared males in mating with released females on Sanibel Island near Ft. Meyers, Florida. It was assumed that native screwworm flies would be scarce and produce few egg masses because no livestock were on the island. However, native screwworms were found to be as numerous on the island as on the mainland and to infest feral cats, opossums, and

rabbits. Evaluation of the releases showed that lab-reared flies performed well in nature, since a high ratio of sterile to fertile egg masses was collected from the wounds of sentinel animals. During the following winter, 1952-1953, when only sterile males were released at a rate of 100 per mi^2, egg mass sterility temporarily reached 100% within the first eight weeks. However, during the 12^{th} 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 sustained because of screwworm fly migration.

The use of sterile males to achieve eradication had to be evaluated on a fully isolated island, small due to our very limited budget. Vieques, nine miles from Puerto Rico, met these requirements but it was a U.S. Navy bombing range. Fortunately, B. A. Bitter, a Dutch agricultural officer, focused our attention on Curacao, Netherlands Antilles, forty miles north of Venezuela. Bitter wrote to the USDA Entomology Research Division for recommendations on protecting dairy and grazing animals from the screwworm. At Knipling's behest, I was dispatched to Curacao in July 1953 to investigate its suitability for our test. It had a serious screwworm problem dating back at least ninety years. About 25,000 goats, 5,000 sheep, 300 deer and numerous rabbits populated the island. Due to the screwworm, many of the nanny goats had only one kid or none. Dairy cattle and horses were not considered significant screwworm hosts because of close surveillance and care by the owners.

Curacao

The eradication test began on March 17, 1954. Initially, egg mass data were collected from screwworm-infested goats maintained in ten pens distributed throughout the island. Additional pens were established later. During the first two weeks prior to the release of sterile flies, 288 egg masses were collected. All of them were fertile, indicating that unmated females did not oviposit and the egg collection and incubation techniques were adequate. For the first six weeks, 200 irradiated flies of both sexes were released per mi^2 and weekly egg masses collections increased from 121 to 277. An average of only 15% of these egg masses was sterile, so the release rate was insufficient to suppress the pest population. Based on this result, we compared two release rates, 200 per mi^2 on one half and 800 per mi^2 on the other half of the island. During the 3rd week of this test, the higher rate resulted in 53% and the lower 28% sterility.

Beginning on August 9, 1954, the entire island was treated weekly with about 800 sterile flies per mi^2, although there were some fluctuations in the supply of sterile flies from the rearing facility at Orlando. During the next four weeks, egg masses averaged only 4.6 per pen and sterility increased from 69% to 79%, reaching 100% by the 7th week. When sterility reached 100% and almost no egg masses were collected, 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 reports. The last two small sterile egg masses were collected after four weeks of zero collections. These were 2nd or 3rd ovipositions by long-lived screwworm females, verified by several eggs in each mass that developed to the spined stage characteristic of the sterilizing dosage delivered to released males. Only small single, sterile egg masses were collected during the 13th and 14th weeks; however, releases were continued through the 22nd week to assure eradication.

These remarkable results were in close agreement with projections made with Knipling's model (Knipling 1959, 1979). Eradication was achieved by increasing the release rate while the native screwworm population was in a natural seasonal decline. Interestingly, Bushland was concerned that we would eradicate the screwworm from Curacao before gaining detailed scientific information about the pest's population dynamics and other factors contributing to the success or failure of SIT. Knipling and Lindquist were confident that the technique was scientifically valid but they thought the project might fail because of operational difficulties. I felt we had at least a 50% chance of succeeding.

When eradication seemed imminent, I asked 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 that makes them much more attractive to screwworms than un-infested wounds. Before the goats were removed from this secure compound and transported to the ten or more pens used to collect egg mass data, all larvae were removed from the wounds and killed with benzol. To increase surveillance during the final weeks of the test, additional pens were established in the lower southern part of the island. Although a few sterile egg masses were collected during the first two weeks, the number quickly dropped to zero.

Procedures were immediately established to prevent re-infestation of the island. Through the news media, radio and print, we requested that livestock owners report any screwworm larval infestations. Nine cases were investigated from mid-October to mid-December and all were identified as *Callitrogra macellaria* (Fabricius), the secondary screwworm fly, a scavenger of minor importance. However, in 1971, seventeen years after

eradication, screwworms were rediscovered on Curacao. This reintroduction probably came from infested livestock shipped from South America to be slaughtered at the abattoir. These screwworms were eradicated by October 25, 1977 by first using the screwworm adult suppression system (SWASS), a lure and insecticide combination. It was applied for ten weeks and suppressed the population by 65-85% before releasing sterile males to achieve eradication (Coppedge et al. 1978).

The screwworm colony was less than ideal. An old strain from Texas was used because the overworked crew at Orlando, led by Jack Graham, Don Hopkins, and Frank Dudley, did not have time to colonize a strain from Curacao. Additionally, we discovered that the first 3rd of the flies to emerge in a batch were predominantly females and the last 3rd were mostly males. The early part of each weekly batch was irradiated and sent to Curacao, while the pupae latest to emerge were reserved for egg production. As a result, the colony cages contained a high proportion of males. Males are highly aggressive sexually, so females die prematurely and produce few eggs when they are greatly outnumbered by males (Baumhover 1965).

In 1954, sterile flies were released from a single engine, World War II training plane. Later, off duty pilots of the Royal Dutch Airline, KLM, flew the screwworm plane but, surprisingly, some became airsick and others eventually had different priorities for their time. Fortunately I was able to enlist the services of Peter Mijs, an adventurous former British Royal Air Force pilot. He was ready on a moments notice but we had to detour from the screwworm flight lanes to photograph incoming oil tankers, so his partner could later board the ships to sell photos to the crew.

We are deeply indebted to the Curacao Administration for helping us to conduct this historic experiment. Bitter was assigned to the project full time and helped immeasurably by procuring goats, securing the cooperation of landowners, solving technical problems, assisting with routine fly releases, and collecting egg masses. The local government also furnished a caretaker who fed and watered our goats. KLM gave priority to our fly shipments from Orlando and assured that they always arrived on time, even during the Christmas Holiday.

Florida 2000 Mi^2 Test

I reported the success on Curacao at the 1956 Florida Livestock Association meeting in Sarasota. My unofficial view was that SIT could be used to rid Florida and the Southeast of the screwworm (Scruggs 1975). Apparently, my report caused the Florida Livestock Board to insist that the USDA draft a proposal for a Florida and Southeastern U.S Screwworm Eradication Program. The proposed program would require an enormous, two-year "all-out" effort to produce, irradiate and release about 50 million sterile flies per week throughout 50,000 mi^2. By contrast, the Curacao project required less than 200,000 flies weekly and involved only 170 mi^2, less than 1% as large as required in the southeastern U.S. As an initial step, SIT was tested in a 2,000 mi^2 area southeast of Orlando, bordering the Atlantic Coast (Baumhover 1958; Baumhover et al. 1959; Graham & Dudley 1959). This was a cooperative effort of the Florida Livestock Board, and the USDA Animal Disease Eradication Division and Entomology Research Division.

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

Beginning May 2, 1957, two million sterile flies were released weekly, at a rate of 1,000 flies per mi^2, against a dense wild population that was infesting 80-100% of newborn calves (Meadows 1985). Despite the severity of this screwworm outbreak, the number of egg masses in the release area declined from 575 per week to only 17 during the 16th week ending August 24, 1957. Egg mass sterility had risen to about 70% by August 10 and there also was a decline in egg masses at check pens south and west of the release zone. If egg mass sterility under these circumstances had reached only 50%, the test would have been considered a success (Knipling 1985). However, egg masses remained numerous in the north and, since the test area was not isolated, eradication could not be achieved. Trends in the egg mass collections mimicked those on Curacao, so the test was ultimately considered successful and some livestock owners, government officials, and Florida legislators were convinced that eradication was feasible in Florida.

Eradication in Florida and Southeastern United States

The dreaded screwworm fly was not present in Florida prior to 1933, having been introduced into

southern Georgia with infested cattle from the drought-stricken Southwest. It spread southward to Florida, infested the entire state within three years, and caused catastrophic losses (Bruce and Sheely 1944). An estimated 75,000 screwworm cases occurred in south Georgia during 1933, and Florida had 1,300,000 in 1934. Expensive state and USDA control programs aimed at treating infested animals reduced the cases to only 48,737 during 1936 and the mortality of animals declined from 12% during 1934 to only 0.71%. This type of control is essential to screwworm eradication by means of SIT, particularly when conditions are ideal for an increase in the pest population. This 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 the screwworm but, despite the success of the 2,000 mi^2 test, the USDA insisted on more research. Consequently, the print media criticized the USDA "for dragging its feet" and a conference was arranged with Governor Collins of Florida. Knipling told him that two additional years of research would save the program $2 million a year. Collins replied, "why wait two years to save $2 million when losses are $10 million per year?" Some cattlemen estimated annual losses at $20-40 million (Knipling 1959). Governor Collins' response deeply affected Knipling's philosophy regarding the importance of areawide 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 screwworm eradication program.

The operational program was initiated in 1957-1958 during the coldest winter ever recorded in the Southeast. Screwworms were killed southward to a line extending from Tampa to Vero Beach. To take advantage of this weather, in December 1957 USDA officials rapidly expanded the research facilities at Bithlo to produce a maximum of 13 million flies per week for use in preventing re-infestation of Georgia and the northern half of Florida (Bushland 1960). From January 18 to April 1, 1958, weekly production averaged only three million flies that were released at a rate of 200 per mi^2 primarily in a band across the peninsula between Gainesville and Orlando. Subsequently, production increased to 14 million flies per week that were released at the same rate across the northern half of Florida and north to Savannah, Georgia to combat scattered outbreaks north of the overwintering line. Sterile flies were also released as far north as Montgomery County, Alabama and south to Miami.

Unfortunately, quarantine lines had not been established in Florida and along the Mississippi River from screworm infested areas in the southwest and southern Florida into screworm free areas in the southeast and northern Florida. With adequate quarantines, sterile flies from the Bithlo facility alone might have eradicated screwworms from the much-reduced overwintering zone. Due to the new infestations, however, an additional large, expensive mass rearing facility was required. A highly talented USDA engineer, C. N. Husman, designed the facility at a World War II airbase seven miles east of Sebring (Baumhover et al. 1966). Husman frequently consulted the research team to determine optimum holding and handling conditions for the insects, and we urged him to enlarge the requested facilities. He surreptitiously, but wisely, increased production capacity by an essential 50%. After the program began, as many as 80 million flies were produced weekly to cover 85,000 mi^2 during peak activity.

Screwworms were only a minor problem throughout the southern half of Florida during the entire program, except for Broward, Palm Beach and Miami-Dade counties. The temperature and rainfall in these counties supported screwworm development and survival throughout the year but the pests were most abundant during the winter when most of the calves were born. Only 19 confirmed and 16 additional cases were recorded in these counties from January through August 1958, 35 weeks with a weekly average of 1.0. However, during September 1958 the average increased to 4.75 and peaked at 33.0 between mid December 1958 and mid January 1959 (Table 1). The percentage of infested wounds peaked at 5.86% during this same period. However, by February 19, 1959 the last infestation was recorded as a mass of 40 eggs, some fertile, taken from a 1-day-old calf. An additional 23 sterile egg masses were collected before March 13, 1959: four of these contained six eggs or less and two had malformed eggs, indicating they were oviposited by released females. Similar data were obtained from Palm Beach and Miami-Dade counties. Palm Beach had 32,434 wounds inspected with only 35 cases (0.15%); Miami-Dade had only 3,321 wounds with 30 cases (0.90%). Although egg mass sterility was 74.5-76.3% for eight weeks from November 23, 1958 to January 17, 1959, time for almost three generations, a substantial downturn in cases did not occur until mid February 1959, after weekly release rates had been increased from 400 to 10,600 sterile flies per mi^2.

There were many possible causes for the screwworm outbreak in the Broward County. The sterile flies could have been of poor quality (Sharman 1960) and there was considerable complacency among the cattlemen. Some ranchers decided prematurely that eradication had been achieved and no longer treated infested calves, allowing larvae to leave wounds, pupate and later emerge as fertile flies. Calf navels accounted for 415 out of 491 (84.5%) screwworm collections made from November 17, 1958 to March 13, 1959,

TABLE 1. AVERAGE NUMBER OF WOUNDS OBSERVED AND SCREWWORM CASES, NUMBER OF EGG MASSES COLLECTED AND INSPECTORS, AND RELEASE RATES EACH WEEK DURING THE SCREWWORM OUTBREAK IN BROWARD COUNTY, 8/30/58 TO 2/28/59.

	Weekly Averages							
Dates[a]	Wounds	Cases	% Wounds Infested[b]	Total Egg Masses	No. Sterile Egg Masses	% Sterile Egg Masses	Inspectors[d]	Rates
8/30-9/27/58	689	4.75	0.69				1.0	400
9/28-10/25/58	635	8.00	1.26				1.0	1150
10/26-11/22/58	922	20.50	2.22				1.0	1875
11/23-12/20/58	1,023	22.00	2.15	55	41	74.5	5.5	3600
12/21-1/17/59	563	33.00	5.86	131	100	76.3	5.2	4300
1/18-2/14/59	384	9.75	2.54	44[c]	39	88.6	9.2	10600
2/15-2/28/59	442	0.50	0.113	1[f]	0	0	4.0	10600
Total	17,756	384.00	2.2					

[a]All periods except the last are 4 weeks.
[b]Includes both confirmed and reported cases.
[c]Includes collections only from 1/18-26/59 when released females began ovipositing sterile eggs due to anoxia.
[d]Number of inspectors collecting samples of larvae from wounds. As many as 15 inspectors were present during the final phases to increase surveillance and spray infested herds.
[e]Number of sterile males released per mi^2 per week.
[f]Last evidence of native screwworm activity, a fertile egg mass from the navel of a 1-day-old calf.

including both egg masses and larvae. More than 36% of the wounds had mature 3rd instar larvae ready to pupate. One cattleman inherited another ranch and unsuccessfully attempted to maintain screwworm control without employing enough laborers. As a result, he was one to two weeks late in treating his newborn calves. A livestock inspector advised another rancher that many animals in his herd were infested yet the rancher delayed treating them for two weeks. Another rancher simply did not treat infested animals. A wildlife refuge within the problem area contained feral hogs that are 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. Finally, the supervisor of airplane release operations unilateral decided to not disperse flies over metropolitan areas until screwworms were out of control.

On June 18, 1959, a confirmed screwworm sample was received from a ranch within ten miles of the Sebring mass rearing facility. The true origin of the specimens was never determined. Screwworms may have escaped from a load of 100 Texas cattle transported by train and held on a ranch near the screwworm facility several weeks before the infestation was reported. Alternatively, fertile screwworms may have escaped from the facility, either accidentally or through sabotage by an employee as a means of extending a well paying job. Ranchers have been known to retain screwworm samples for later use to "test surveillance by program personnel", or to obtain free CO-RAL to treat a herd for various other insect pests and ticks. Finally, the rancher may have inadvertently delayed submission of the sample.

In conclusion, early development of SIT through screwworm eradication in Curacao, Florida and the southeastern U.S. demonstrated the importance of close collaboration among scientists, industry leaders and government officials at all levels. Progress depended on acceptance of new ideas and willingness to take reasonable risks. Florida had 865 confirmed screwworm cases during the eradication period and, of these, 31 occurred more than 50 miles above the overwintering line (Baumhover 1966). Additionally, 1901 cases were reported but not confirmed of which 1,711 (90%) were probably screwworms (Knipling & Rainwater 1937). Thus, the total number of cases probably was about 2,575, or 0.08% of a possible 3 million cases that would have occurred without releasing sterile screwworm flies. Eradication of the screwworm from the southeastern U.S. was declared in November 1959, as this extremely creative, low risk, and cost effective eradication program was completed successfully.

References Cited

Baumhover, A. H. A. J. Graham, B. A. Bitter, D. E. Hopkins, W. D. New, F. H. Dudley, and R. C. Bushland. 1955. Screwworm control through release of sterilized flies. J. Econ. Entomol. 48(4): 462-466.

Baumhover, A. H. 1958. Florida screwworm control program. Vet. Med. 53(4): 216-219.

Baumhover, A. H., C. N. Husman, C. C. Skipper, and W. D. New. 1959. Field observations on the effects of releasing sterile screwworms in Florida. J. Econ. Entomol. 52(6): 1202-1206.

Baumhover, A. H. 1965. Sexual aggressiveness of male screwworm flies measured by effect on female mortality. J. Econ. Entomol. 58(3): 544-548.

Baumhover, A. H., C. N. Husman, and A. J. Graham. 1966. Screwworms. In Insect Colonization and Mass Production, pp. 533-554. Academic Press, Inc., New York.

Bushland, R. C. 1952. Screwworm control. Cattleman 38(12): 34-36, 38.

Bushland, R. C. 1960. Male sterilization for the control of insects pp. 1 - 23 in R. L. Metcalf (ed.). Advances in Pest Control Research, Volume III, Interscience Publishers, New York.

Bushland, R. C., and D. E. Hopkins. 1951. Experiments with screwworm flies sterilized by X-rays. J. Econ. Entomol. 44(5): 725-731.

Bushland, R. C., and D. E. Hopkins. 1953. Sterilization of screwworm flies with X-rays and gamma rays. J. Econ. Entomol. 46(4): 648-656.

Coppedge, J.R., J. L. Goodenough, A. B. Broce, F. H. Tannahill, J. W. Snow, M. M. Crystal, and H. D. Petersen. 1978. Evaluation of the screwworm adult suppressions system (SWASS) on the island of Curacao. J. Econ. Entomol. 71(4): 579-584.

Graham, A. J., and F. H. Dudley. 1959. Cultural methods for mass rearing of screwworm larvae. J. Econ. Entomol. 52(5) 1006-1008.

Knipling, E. F., and H. T. Rainwater. 1937. Species and incidence of dipterous larvae concerned in wound myiasis. J. Parasitol. 23(5): 451-455.

Knipling, E. F. 1955. Possibilities of insect control or eradication through the use of sexually sterile males. J. Econ. Entomol. 48(4): 459-462.

Knipling, E. F. 1959. Screwworm eradication: Concepts and research leading to the sterile-male method. In Smithsonian Report for 1958. pp. 409-418. Smithsonian Institution, Washington.

Knipling, E. F. 1979. The basic principles of insect population suppression and management. USDA Agriculture Handbook 512.

Knipling, E. F. 1985. Sterile insect technique as a screwworm control measure: The concept and its development. *In* Symposium on eradication of the screwworm from the United States and Mexico. O. H. Graham (ed.). Misc. Publication No. 62. Entomol. Soc. Amer.

Laake, E. W., E. C. Cushing, and H. E. Parish. 1936. Biology of the primary screwworm fly. *Cochliomyia americana*, and a comparison of its stages with those of *C. macellaria*. U.S. Dep. Agric. Tech. Bull. 500. 24 pp.

Meadows, M. E. 1985. Eradication Program in the Southeastern United States. *In* Symposium on Eradication of the screwworm from the United States and Mexico. O. H. Graham (ed.). Misc. Publication No. 62. Entomol. Soc. Amer.

MELVIN, R., AND R. C. BUSHLAND. 1936. A method of rearing *Cochliomyia hominivorax* C. & P. on artificial diet.

MELVIN, R., AND R. C. BUSHLAND. 1940. The nutritional requirements of screwworm larvae. J. Econ. Entomol. 33(6): 850-852.

MEYER, N., AND O. SIMPSON (eds.). 1996. History of the Mexico and United States Screwworm Eradication Program. Vintage Press, New York. 367 pp.

MULLER, H. J. 1950. Radiation damage to genetic material. American Scientist. 38:33-59,126.

SCRUGGS, C. G. 1975. The peaceful atom and the deadly fly. Jenkins Publishing Co., Austin, TX. 311 pp.

SHARMAN, R. S. 1960. Screwworm eradication in the Southeast. Cattleman 46(11): 25-28.