Zoonosis Update

Screwworms

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Two species of primary screwworm flies exist in the world. The Western Hemisphere is home to the NWSF. The genus and species designation for this parasite underwent a number of name changes before the current term, *Cochliomyia hominivorax*, was established.[1–3] The adult fly may be 8 to 10 mm in length,[1] with a yellowish-orange face and 3 dark, longitudinal stripes on the thorax (**Figure 1**).[4] *Chrysomya bezziana*, the OWSF, resides in the Eastern Hemisphere and may be 8 to 12 mm in length.[1,4] In contrast to the NWSF, the adult OWSF is green to blue with no more than 2 dark, longitudinal stripes on the thorax.[4] Both species cause myiasis (the infestation of tissue with fly larvae) in humans and other animals.

In 1966, NWSF populations capable of sustained reproduction were eradicated from the United States by means of the SIT, but periodic incursions have occurred.[5] The last natural incursion into the United States was from Mexico, which occurred in Starr County, Texas, in August 1982.[6] Since that time, the flies have reentered the United States as passengers on pets, people, and livestock.[5,7–12] In 2002, the USDA APHIS Veterinary Services estimated that an uncontrolled reintroduction of this pest would result in annual losses to the livestock industry of $750 million.[5] Although the SIT should work equally well on OWSF populations, no sustained attempts at eradication have been made to date. An SIT program was being evaluated in Iraq in the late 1990s,[13] but was hindered by United Nations sanctions and then interrupted by the current military action.[14–16]

Within the last 18 years, OWSFs have begun to move out of the species' normal range.[13,17,18] Likewise, NWSFs have begun to appear in exotic locations. Introduction of the NWSF larvae into countries in the Eastern Hemisphere by movement of animals or humans has been documented to have occurred at least 6 times.[6,13,19–25] In 5 instances, only larval stages were detected and quickly eliminated. However, the larval stage apparently escaped detection in Libya, where the NWSF established a self-sustaining population of adults.[6,13,21] Although OWSFs have not been detected in the Western Hemisphere, 4 other species of *Chrysomya*, all of which are normally Old World inhabitants, have been found in the Americas on at least 4 occasions.[26] This transfer of *Chrysomya* spp, other than the OWSF, to the Western Hemisphere and the documented ability of *C bezziana* larvae and flies to be transported by people, animals, ships, and aircraft[27,28] indicate that there is potential for OWSF populations to become established outside of the Eastern Hemisphere.[26]

Figure 1—Photograph of a female NWSF (*Cochliomyia hominivorax*; dorsolateral view). The adult may be 8 to 10 mm in length. (Photographed by M. Campos Pereira, University of São Paulo, Brazil. Reprinted with permission. Available at: icb.usp.br/~marcelcp/Imagens/f-zen9.jpg. Accessed Feb 17, 2005.)

In this article, biologic features of NWSFs and OWSFs, the history of NWSFs in the United States and the NWSF eradication program involving the SIT, the current status of NWSF populations in the Western Hemisphere, incursions of NWSFs into the Eastern Hemisphere and areas from which the species has been eradicated in the Western Hemisphere, new developments in the detection of screwworms and prevention of infestation, and recent developments involving OWSFs in the Middle East will be reviewed.

Biological Features

The larvae of both NWSFs and OWSFs are commonly called screwworms because of the shape and

NWS	New World screwworm
NWSF	NWS fly
OWS	Old World screwworm
OWSF	OWS fly
SIT	Sterile insect technique
APHIS	Animal and Plant Health Inspection Service

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characteristics of the second or third instar larvae.[6] They are considered primary screwworms because of the obligatory myiasis they cause in mammals.[29] Larvae of both species have tusklike mandibles that tear flesh (**Figure 2**). The mature NWSF larva may reach 17 mm in length, while its Old World counterpart may reach 18 mm in length.[1] In addition, there are 2 species of secondary screwworm flies, *Cochliomyia macellaria* (in the Western Hemisphere) and *Chrysomya megacephala* (in the Eastern Hemisphere). The larvae of those 2 species cause facultative myiasis and are called secondary screwworms because they infest a wound only after a primary screwworm has initiated tissue damage.[29]

Fresh wounds on mammals attract gravid NWSF and OWSF females that oviposit 100 to 300 eggs on dry margins of wounds. The gravid females obtain nutrition by feeding on wound exudates. Although it mates only once, a female may lay as many as 3,000 eggs during its lifetime. Eggs hatch after a 10- to 20-hour incubation period, and the larvae begin feeding on the host's live flesh. Maturation of the larvae occurs after 4 to 12 days.[29] During this time, the wound develops a distinctive odor that attracts more gravid females[30] that lay additional egg masses. The larvae pupate after dropping to the ground and burrowing into the soil, and the adults emerge in approximately 3 to 5 days.[5]

Wounds that become invaded by gravid NWSF and OWSF females may be as small as a tick or insect bite. The Gulf Coast ear tick (*Amblyomma maculatum*) posed a particular problem in southern Texas because of its preferred attachment site on the pinna of the ear.[31,32] Many bovids in South Texas have lost portions of ears as a result of the combined actions of *A maculatum* and screwworms. Any wound, such as a wire cut or a scratch from a thorn, can be enough to create an attractive site for NWSFs.[32] The author recalls picking larvae out of navels of many newborn calves and lambs as well as from periodontal areas of a calf that ran into a fence and lacerated its gingival tissue. Injuries to gingival tissues are common in many species and can become infested with screwworms (**Figure 3**).

In addition to naturally occurring wounds and openings, such as the navel, eyes, and nares, routine management practices such as dehorning, docking, castration, and branding create sites for oviposition. Consequently, calving, lambing, and wound-inflicting management practices are best planned for the coolest weather when fly activity is nonexistent or at its lowest level.[6,32] In the southeastern states, screwworm myiasis among animals decreased from 1.3×10^6 cases in 1934 to $< 5 \times 10^4$ cases in 1936,[32] which was in part due to alteration in the timing of management practices that created wounds.

In all species, the most severe screwworm infestations have involved multiple egg depositions, producing as many as 3,000 larvae in a single wound; these infestations were most likely to cause death within 7 to 10 days if untreated, as a result of the migration of larvae deep into the host in search of living tissue.[5] When screwworm populations are unchecked, frequent examination of animals, with cleaning and treatment of infestations, is required to prevent losses among livestock. This very labor-intensive practice is prohibitive in the United States, in today's economic conditions. As an example of the amount of time required to monitor and treat screwworm infestations, especially in the southern and southwestern United States, prior to the effective application of the SIT, Chaunce Thompson, a rancher from Stephens County, Texas, stated, "For 8 to 10 months a year, we did little else but doctor screwworms."[33] In the early 1980s, a

Figure 2—Photograph of a NWS larva. Mature NWS larvae may reach 17 mm in length. Notice the tusklike mandibles protruding from the screwworm's mouth with which it rasps the flesh of living warm-blooded animals. An infested wound may contain hundreds of such larvae. (Photographed by J. Kucharski, USDA Agricultural Research Service. Reprinted with permission.)

Figure 3—New World screwworm larvae in the mouth of a sheep. (Photographed by M. Campos Pereira, University of São Paulo, Institute of Biomedical Sciences, Department of Parasitology, São Paulo-SP, Brazil. Reprinted with permission [arrows added by author].)

survey of producers in several Caribbean islands revealed a similar intensity of activity, though on a smaller scale, with respect to animal examination and treatment because of NWSF infestation.[34]

Both NWSFs and OWSFs are limited in their natural range by temperatures during winter. The original range of NWSFs was between the latitudes of 35° and –35° in the Western Hemisphere,[23] with a similar range for OWSFs in the Eastern Hemisphere.[3,35] Affected regions within the historical range of OWSFs were Southeast Asia; Kuwait; the Indian subcontinent; Papua New Guinea; tropical, sub-Saharan Africa; Oman; Muscat; and Fujaira.[36]

Fly strikes are a summer phenomenon in temperate areas, whereas they are continuous in tropical areas.[29] In the warmer months of the year, cases of screwworm infestation were often reported in the central states of the United States, with occasional reports of cases near the border with Canada.[37] Infestations in areas outside of the usual range of NWSFs appear to be most often results of transportation of infested animals from the areas in which the flies are endemic.[5,6,13] The initial year of the eradication campaigns in Florida and Texas benefited by a winter season that was colder than usual, which reduced the sterile fly distribution area.[6]

Because of their environments, livestock and wildlife develop infestations most frequently, although humans are also susceptible to infestation of wounds. The medical literature contains numerous reports[1,2,32,38–43] of human infestations with NWSF larvae in the United States during the decades of the 1930s, 1940s, and 1950s. Many of those cases involved the nasal passages and sinuses,[2,32,38,40,41,43] to the extent that NWSFs are referred to as the cause of nasopharyngeal myiasis in humans.[44] One Texas farmer is reported[32] to have expelled 385 larvae from his nostrils during a 9-day period, whereas approximately 500 larvae were removed from the nasal passages of a man in Arizona during an 8-day period.[43] Frequently, death or disfigurement were sequelae to human infestations in the United States[32,38,41,43] and remain consequences of infestation among humans in areas where the 2 fly species are active.[45–51]

During 1935, when there was a high incidence of NWSF-associated myiasis among livestock, it has been estimated that at least 100 human cases of myiasis occurred; the next year, after a control program reduced infestations among livestock, only 8 humans were reported to be affected.[32] Although American scientists of that decade concluded that humans were incidental hosts and had a lower rate of infestation than did livestock,[32] 2 British scientists of the same era concluded that humans were the preferred host and cattle were the incidental host. However, the latter did qualify their observation as possibly being biased because medical practitioners had submitted nearly all of the specimens the researchers had received.[3]

The SIT eliminated NWSFs as a cause of myiasis in the United States, but NWSF-associated myiasis remains a risk for people who travel to areas in which the flies are endemic.[8,10] In addition, the parasite continues to be a human health risk in Central and South America, where fly populations remain largely uncontrolled. The US Embassy in Costa Rica stated that program personnel in Nicaragua had documented 138 human cases of NWS-associated myiasis, including 70 children (no time frame provided). Three of those affected persons died, and tissue damage in 2 others resulted in the loss of body parts. In El Salvador from 1990 to 1992, 530 humans affected with NWSF-associated myiasis were reported.[45] Among humans, various anatomic locations are reported as being infested, such as the orbits, nasal passages and sinuses, scalp, ear pinnae, legs, ingrown toenails, male and female urogenitalia, navel, skin, meninges, intracranial spaces, axillae, pharynx, throat, esophagus, and oral cavity.[1–3,8,23–25,32,38–41,43,44,46–48,52–56] Although only 1 report[24] of urogenital NWS infestation in a man was found in the literature (the infestation was diagnosed in the United Kingdom in 1991), a veterinarian assigned to a screwworm eradication program in Central America showed the author a 35-mm slide of a man with a screwworm infestation of the penis.[a]

Many of the documented cases have involved some underlying pathologic change (eg, sinusitis, syphilitic rhinitis, cancer, or periodontal disease) or some incapacitating condition (eg, stroke, cerebral palsy, or alcoholism) that affects the patient's ability to maintain a satisfactory level of hygiene or to obtain treatment for wounds, lesions, or pathologic conditions that may serve as oviposition sites.[32,41,43,44,46–48,52,55,56] Similar reports[49–51,57–59] are available for OWS infestations in various countries, which also document the frequent presence of an underlying pathologic change, especially when the orbits, nasal passages, ears, or oral cavity are involved.

History of NWSFs in the United States

The screwworm was first identified as a livestock pest in the western United States in 1825. As the US livestock industry developed, the NWSF became a cause of major livestock industry losses in the southwestern states. In 1930, a multiyear drought began in the states of the southern plains and southwestern region. This prompted movement of livestock from those areas to the southeastern states, thereby introducing the NWSF into Florida, where it caused annual livestock industry losses in excess of $400 million.[5,41] The southern portion of Florida is at a latitude that enabled screwworm populations to over-winter. Prior to the movement of affected livestock, the insect had not been able to migrate eastward far enough to establish over-wintering populations.

Because of these losses, Edward F. Knipling was assigned in 1931 to conduct research at Menard, Tex, on the biological features and control of screwworms.[60] To assess the importance of NWSFs in the development of myiasis, Knipling and Rainwater analyzed 901 samples of larvae from human and animal wounds submitted from the southern and western United States in 1935 and 1936; most samples originated in Georgia, Florida, South Carolina, Alabama, and Louisiana, and approximately 90% of the larvae were NWS.[42]

In 1937, Raymond C. Bushland joined the research team in Menard and its investigations revealed that a female NWSF mated only once in its lifetime, whereas

the male mated promiscuously.[60,61] By 1938, Knipling had formulated the theory of NWSF control by use of sterilized males.[60–62] The missing element was a method of sterilization that would not inhibit the vitality of the male flies. In 1950, Knipling was apprised of fruit-fly research whereby sterilization was induced by use of X-rays. Bushland and Hopkins began experiments on NWSF larvae, using the X-ray equipment at Brooke Army Hospital in San Antonio, Tex.[60–62] The experiments proved that male NWSFs could be successfully sterilized without inhibiting their libido. The next challenge that Bushland overcame was developing a mass-rearing protocol. During that time, he also worked on improving the sterilization technique.[60,61]

To test Knipling's mathematical models regarding the number of flies and the frequency of distribution required for control of the NWSFs, Sanibel Island was selected as a test site. Sterilized male NWSFs were distributed on this island (area, 38.8 km^2 [15 $mile^2$]), which is located 3.2 km (2 miles) off the west coast of Florida. By the third generation, the local NWSF population was eradicated. However, fertile females from the mainland repopulated the area.[61,62]

A more definitive test was provided in 1954 when the Dutch government requested assistance in controlling the NWSF population on the 440.3-km^2 (170-$mile^2$) island of Curaçao, located off the coast of Venezuela and at least 64.4 km (40 miles) from the nearest land.[60,61] By the third generation, 100% of the egg masses were sterile, and the flies were eradicated by the fourth generation.[61]

The next goal was to apply the technology to the southeastern United States. Mass rearing of flies began in Florida in 1955, and eradication of NWSFs from this area of the country was achieved in 1959 (1 year ahead of schedule). Inspired by the success in Florida, livestock producers in Texas formed the Southwest Animal Health Research Foundation to support an SIT program in the southwestern area of the United States. The program was initiated in 1962.[61,62] In 1966, eradication was declared successful, but incursions from Mexico continued until, in 1982, the last local infestation was eliminated from Starr County, Texas.[6] This USDA program is considered to be the first large-scale, successful application of the SIT in the world[b] and is still considered the best example of an SIT application.[35]

One of the greatest hindrances to controlling the NWSF populations of the southern and southwestern United States was the fact that wildlife served as maintenance hosts for the pest. Although ranchers treated every infested domesticated animal, affected wildlife was generally not captured for treatment. This provided an abundant source of flies to continue plaguing livestock. In the 1930s, Lindquist[63] documented infestation in eastern cottontail rabbits (*Sylvilagus floridanus*), jackrabbits (*Lepus californicus*), opossums (*Didelphis virginiana*), and white-tailed deer (*Odocoileus virginianus*). More than 500 flies emerged from the larvae collected from 1 Texas jackrabbit in that study.[63] Elimination of NWSFs from the southern and southwestern United States is considered a key element in the population explosion of white-tailed deer; it also enabled the development of game ranching in those areas.[64] One consequence of screwworm eradication in the southern states—the rapid increase in the feral hog population—has generated mixed responses. In Texas, there are approximately 1×10^6 feral swine, which is approximately half of the nation's total population. Hunters see this as a positive outcome of screwworm eradication, whereas farmers and ranchers generally decry the destructive nature of these animals.[65]

In 2003, Texas cattlemen were asked what was the most significant event in ranching during their lifetime. The foremost response was "the eradication of the screwworm." Tobin Armstrong summed it up by stating "… if we had to go back and do the kinds of things we did back then as a routine to cope with screwworms, nobody is equipped or prepared physically or emotionally to deal with it. It would be disastrous."[33] The screwworm eradication program probably contributed more than any piece of modern machinery to the reduction of the population of working cowboys by decreasing the amount of labor required on ranches.

Use of the SIT in Mexico, Central America, Panama, and the Caribbean

After multiple incursions of NWSFs from Mexico, the United States and Mexico signed an agreement in 1972 to apply the SIT in Mexico, beginning along the Texas-Mexico border. By 1991, NWSFs were eliminated from Mexico. During 1986 and 1988, Guatemala and Belize joined the eradication effort. Honduras, El Salvador, and Nicaragua were added to the program in 1991, and Costa Rica was added during the next year. In 1994, Panama was also included.[6]

In October 2004, Novy reported[66] to the US Animal Health Association's Committee on Parasitic Diseases that NWSFs had been eradicated from all countries of North and Central America and Panama. In addition, Puerto Rico and the US and British Virgin Islands have also been freed of the pest. However, NWSFs still reside in the Caribbean countries of Cuba, the Dominican Republic, Haiti, Jamaica, Trinidad, and Tobago.[66]

A report[34] published in 1985 stated that 9% to 33% of producers and animal health personnel in Trinidad, Guyana, Surinam, and Jamaica were aware of a human case of NWS myiasis in their country. Furthermore, 82% to 90% of responding livestock owners in Surinam, Guyana, Trinidad, Tobago, and Jamaica had at least 1 animal with NWSF-associated myiasis, and 53% to 78% examined their animals daily for infestations. An SIT program was judged feasible for implementation in Jamaica, Trinidad, and Tobago, but it was considered only applicable in the coastal areas of Surinam and Guyana.[34] The government of Jamaica initiated a control program in 1998. Although the SIT has been successful in all countries where it has been applied with the exception of Jamaica, it has not been successful there thus far because of several factors, including labor disputes, equipment malfunctions, and lack of dedication and interest among key groups. According to Novy's report,[66] if success was not achieved by March 2005, the program might end; this would then more than likely result in a loss of interest in an SIT by the

Dominican Republic. However, the Jamaican Ministry of Agriculture Corporate Plans for 2004-5 and 2006-7 indicate that the Ministry will continue to implement the SIT program beyond March 2005.[67]

Although the USDA funds approximately 80% of the Panamanian SIT as part of the measures to prevent migration of NWSFs back to the United States, no funds are provided for programs in the Caribbean islands. Apparently the threat of a self-sustaining population of NWSFs being transported to the United States from these islands is considered small enough that funding assistance is not provided.[66] However, the movement of tourists from these islands creates some level of risk for the reintroduction of NWSFs to the United States based on other incidents involving unwitting human transport of the larvae to exotic locales.[8,10,22–25,66]

Ironically, in the early 1970s, the island of Curaçao became reinfested. In 1971, infestations were detected in a dog and a goat, but no self-sustaining populations were identified at that time. However, an NWSF population became established in 1975, apparently as a result of importation of noninspected cattle from South America.[68] Eradication was once again achieved in 1977, through the use of the screwworm adult suppression system and the SIT.[69]

Problems in the SIT Program

In 1972, the number of reported cases of screwworms in the southwestern United States dramatically increased.[70] Ranchers and livestock news reporters indicated that livestock and humans were affected. In all likelihood, wildlife species were also affected. Analysis of artificially raised flies used in the SIT revealed that a noncompetitive strain of male NWSFs had been selected, resulting in diminished flight abilities. In addition, Coppedge and Ahrens reported in a personal communication to Bush et al that flies of this genetic line would only mate in the afternoon, leaving the fertile native males free of competition during their morning mating period.[70]

In February 2003, Panama was alerted that as many as a third of the flies in recent shipments from the NWSF production plant in Chiapas, Mexico, had not been sterilized. Increased surveillance and dispersal of sterile flies were implemented.[71] In the same month, screwworm cases attributed to the same problem were reported in Chiapas itself.[72]

Incursions of NWSFs into the United States Since 1982

In 1987, hunting dogs returning to the United States from Honduras and Venezuela were found to be infested with screwworms; in the following year, screwworms were detected in a horse from Argentina.[12] In 1989, NWS larvae were detected in scalp wounds of a US soldier returning from Panama.[8,12]

In June 1997, a Utah state veterinarian announced that an 11-month-old Rottweiler that had been brought to Utah from Panama was infested with screwworms. A private practitioner found the larvae during an examination of the dog. Prompt action apparently prevented further spread of the pest.[7] In November of that year, screwworm larvae were detected in a foot lesion of a dog that arrived in San Antonio, Tex, from a military base in Panama. A private veterinary practitioner collected the larvae and submitted them for identification. Again, prompt action was taken to ensure none of the larvae reached maturity. All areas where the dog had traveled en route were inspected and treated.[9]

Shortly after his return to Alabama from Brazil on July 31, 1998, a man sought treatment for maggots in his scalp; the maggots were identified as NWSF larvae.[10] Because no animals were subsequently reported to be infested, the livestock industry once again escaped a disaster.

In October 1998, an alert rancher in Edwards County, Texas, submitted 9 larvae collected from a wound on an Angora goat for identification; 1 was identified as an NWSF larva.[73] No more larvae were found when more than 40,000 livestock and some ranch dogs were inspected.[74] No infestations were found in the spring when warmer temperatures would have favored fly activity.

Seventeen horses from Argentina were processed through a USDA APHIS quarantine center in Miami on February 27, 2000, and were then shipped to Georgia, California, Pennsylvania, Texas, and Florida. On March 2, 2000, a private practitioner in West Palm Beach found screwworm larvae in one of the horses. Alerts were issued by USDA APHIS to veterinarians in the states to which the horses had been transported, and foreign animal disease investigations were conducted. No larvae were found in any of the other horses.[11] As a consequence of this incident, on March 23, 2000, USDA APHIS implemented a 7-day quarantine and inspection process for all horses imported from Argentina, which was eventually expanded to horses from countries in which NWSFs or OWSFs are endemic.[75,76]

NWSs in the Eastern Hemisphere

Screwworms from the Western Hemisphere have been transported to the Eastern Hemisphere on several occasions. In a letter to the *Veterinary Record* in 1989,[19] Chermette recalled a case of otitis in a dog that was a result of infestation with *C hominivorax* larvae in Paris in 1982. The dog had recently arrived from Brazil, where it presumably had become infested.

In 1988, NWSFs were discovered in Libya.[6,13,21,77] The introduction of the flies is thought to have been accidental, probably through the importation of livestock from an area in which NWSFs are endemic, such as South America.[6,21] During the next 3 years, a broad range of animal species was affected, including humans.[77,78] A 20,000-km^2 (7,722-mile^2) area around Tripoli was affected before eradication was achieved, at a cost of $75 million (US), in 1991.[13,20] The project was sponsored by the Food and Agricultural Organization of the United Nations and involved dispersal of more than 1.3×10^9 sterilized NWSFs across a 41,000-km^2 (15,830-mile^2) area (the affected area plus a buffer zone), thereby assuring eradication.[21]

Because Egypt borders Libya to the east, Egyptian veterinary officials instituted an intensive surveillance and prevention program involving inspections, larvae submissions, insecticide treatment of wounds, and

public education. Ports of entry adopted strict quarantine measures. Efforts were most intense in the northwest part of Egypt.[77]

Two days after having returned from a 3-week visit to Trinidad, a female resident of the United Kingdom was evaluated by a physician in December 1998. The patient complained of scalp ulcers, fever, malaise, and movement under her scalp. Examination revealed active larvae in the lesions. During a 72-hour period, 91 NWS larvae were removed. No complications were reported with the patient's recovery.[22]

In 1992, an Australian woman who was returning from a trip to Brazil and Argentina sought treatment in Auckland, New Zealand, for 2 lesions in the dorsal area of her neck and suboccipital region. Several immature maggots were removed; the physician advised treating the lesions with fly spray, the application of which caused approximately 50 maggots to emerge and die. Later, on the same day, the patient was examined by a physician in Australia, who removed additional maggots and prescribed the application of disinfectants and topical antimicrobials. Two days later, a third physician prescribed irrigation of the wound with hydrogen peroxide. The woman's husband flushed at least 2 more maggots from the lesions. Four days after the lesions were discovered, a veterinary pathologist at a regional laboratory was consulted and made a presumptive diagnosis of *C hominivorax* larvae. The Commonwealth Scientific and Industrial Research Organization Division of Entomology in Canberra confirmed the identification. Although a population of the flies was not established, both New Zealand and Australia were at risk of having NWSFs introduced through this traveler's infestation and subsequent inadequate treatment protocols.[25]

A 41-year-old Finnish man participated in an international adventure sports race in the Brazilian jungle in November 2001; during the race, he received a wound to his arm. Preliminary cleansing involved removing dirt, gravel, and 3 unidentified winged insects. First aid treatment was obtained 3 hours later, and further cleansings of the wound were hastily performed during the next 108 hours of the race. During his return to Finland, a larva emerged from the wound while the traveler was at the airport in Frankfurt, Germany. The Finnish Museum of Natural History identified the specimen as a third-stage NWS larva.[23] Shoaib et al reported[24] the first case of urologic infestation with NWS larvae in a human in the United Kingdom. The patient was a 79-year-old male who had vacationed in Venezuela; he had a scrotal lesion from which 40 larvae were removed. These incidents highlight the risk that international travel poses with respect to the introduction of exotic organisms into any country. Awareness of infestation risks should be heightened among travelers to locales where NWSFs naturally exist, to reduce the risk of transporting a sustainable population of such flies into currently unaffected areas.

Private practice, government-employed, and military veterinarians in countries that import livestock or other animals from areas in which NWSFs are endemic and physicians who treat travelers from those same areas should consider screwworm myiasis as a differential diagnosis when dealing with nonhealing wounds or wounds infested with maggots.[25,79]

OWSFs in the Eastern Hemisphere

The areas in which OWSFs are endemic are located from tropical Africa to southern China, and as far south as Papua New Guinea.[80] Australia and New Zealand are both free of the pest, but are considered to be at risk of infestations through the movement of animals,[28,81] animal by-products,[82] and people; the latter risk is based on at least 1 documented case of OWSF-associated myiasis in a traveler returning to Malaysia from Sri Lanka.[27] That incident indicates that OWSFs have an ability to hitchhike similar to that of NWSFs.[8,10,22,23,24,25]

From 1985 through 1988, 13 incidents in which *C bezziana* flies were detected on aircraft or ships at Australian ports or airports have been reported.[28] One incident in April 1988 was particularly disturbing because the flies were trapped while a ship was in the port of Darwin; however, based on surveillance conducted within a 50-km (31.1-mile) radius of the port, a population of OWSFs did not become established.[28]

The range of OWSFs began to expand in the mid-1980s to include several Persian Gulf countries.[13] By September 1996, OWS larvae were determined to be a cause of myiasis in Iraq, as reported[14] at the 25th Food and Agricultural Organization Regional Conference for the Near East held in March 2000 in Beirut, Lebanon. Although most infested animals were sheep, other animal species including humans were also affected. Control efforts were hindered by a lack of insecticides (a consequence of United Nations sanctions).[14] In 1998, Iraq requested assistance from the International Atomic Energy Agency for 7 projects, including development of a sterile OWSF program. Lack of International Atomic Energy Agency personnel in Iraq resulted in delayed assistance.[14,15] The development and application of an SIT program was still being evaluated in 1999 and 2000.[13,14] The prospect of an SIT was further set back by Operation Iraqi Freedom. The Middle East Media Research Institute reported on an April 27, 2003, *Al-Jazeera* television interview with Dr. Muhammad Zeidan, an Iraqi scientist employed by the Iraq Nuclear Energy Authority.[16] On the basis of information provided by Dr. Zeidan, by the time Operation Iraqi Freedom was launched in 2003, a sterile fly program was under development. He was also quoted as stating looters had released an unsterilized colony of *C bezziana* at the Iraq Nuclear Energy Authority facility during the United States-led invasion of Iraq. The looting effectively ended any work on developing a sterilization facility in the country. Besides the loss of the sterilization project, at least 2 major obstacles exist to establishing an effective SIT in Iraq: the inability, thus far, to develop a strategy for a program with a positive cost-benefit ratio and the difficulty in securing the cooperation of all nations in the region.[13]

By 1998, Iran and Kuwait were also affected by OWSFs.[17] Efforts to prevent further spread have been undertaken by the aforementioned countries as well as Jordan, Saudi Arabia, and Syria. Increased surveillance

and public awareness and cessation of the movement of livestock across the borders are the key elements of these efforts.[18]

OWSFs in the Western Hemisphere

At present, no cases of myiasis caused by *C bezziana* have been identified among humans and other animals in the Western Hemisphere. However, at least 4 species of *Chrysomya* have become established in the New World.[26] Three of those species have become established in various countries of South America. One species, *Chrysomya rufifacies,* has been located in most of Central America as well as Arizona and Texas in the United States.[26] Because these species were able to be transported to the Western Hemisphere, *C bezziana* could, theoretically, also be translocated.

New Developments in Detection, Treatment, and Prevention

To activate screwworm treatment or eradication protocols, detection of the flies or larvae must first occur. Traditionally, in the United States, this has required submission of larvae to an approved laboratory, which may be a time-consuming process depending on the relative geographic locations of the suspected outbreak and laboratory. At the laboratory, the larvae must be examined under a microscope or be allowed to mature into an adult for accurate identification. This entire process hinders the rapid and accurate diagnosis of screwworm infestations. To overcome these limitations, researchers in Nebraska are developing an ELISA that can use any life stage of the organism to obtain rapid identification with 97% accuracy.[83]

Taylor et al[84] have developed a rapid, inexpensive method of differentiating *C hominivorax* from *C macellaria*. A PCR-restriction fragment length polymorphism technique is used.[84] With this technique, it appears that identification of species can be obtained quickly, especially when the samples are in a condition that would make morphologic identification difficult. If a sample was too decomposed for an accurate identification, there would be 2 choices: inaction or activation of an SIT. If the sample included an NWSF larva and no action was taken, the consequence could be an out-of-control outbreak of the pest; conversely, a waste of resources would result if initiation of an SIT occurred on the basis of an unidentifiable (possibly secondary) screwworm infestation.

A technique that may have use at ports of entry is that of a detector dog for identification of animals infested with NWS larvae. To the author's knowledge, at least 1 such dog has been trained to detect NWS infestation, proving the feasibility of the technique. During 265 test situations involving training dummies, the dog's success rate was 100%; when challenged with 19 infested animals, the dog detected 18 (success rate of 94.7%).[85]

Treatments of myiasis in humans have involved manual removal of larvae, with or without surgery[2,38,39,41,43,48,49,51,52,56,58,59]; irrigation of wounds with physiologic saline (0.9% NaCl) solution, antiseptic solution, or hydrogen peroxide[25,38,40,43,51,52]; coating furunculoid myiasis lesions with petroleum jelly or nail polish to deprive the larvae of oxygen[55]; use of an anesthetic such as chloroform, ether, or benzol to cause the larvae to evacuate the lesion, as well as kill remaining larvae[2,32,38,41,43,56,57]; use of potassium permanganate or boric acid as a deodorant and cleansing agent[43]; and application of cocaine or adrenaline (epinephrine) to shrink the nasal mucosa (cocaine will also provide local anesthesia).[38,41,43] Antimicrobials are frequently administered to eliminate secondary bacterial infections.[23,25,38,51,58,59]

The earliest formulated screwworm treatment was developed in 1937 and 1938[61]; the product was a paste containing diphenylamine (35%), benzol (35%), turkey red oil (anhydrous [6.7%]), and inert ingredients (23.3%).[c] By 1951, a lindane preparation of this treatment was being used.[2] Since then, many other preparations have been developed and used to kill both species of primary screwworm larvae. A mixture of 1% dichlofenthion plus gentian violet and a smear preparation of 3% lindane with pine oil were evaluated by Perkins,[86] who found them effective in repelling OWSFs and preventing restrike of treated wounds but impractical because of the need to reapply the treatments every 48 hours. In 1996, topical application of dicyclanil (an insect growth regulator) was evaluated in Argentina for use in preventing NWS infestation of castration wounds in cattle. A 5% weight-to-volume solution of dicyclanil was applied to the wound surfaces of treated cattle; the treated cattle, along with control cattle, were exposed to NWSFs under natural pasture conditions. Fly strike incidence was similar in both groups, but by day 25 after exposure to NWSFs, significantly fewer cases of active myiasis were identified in the treated group, compared with the control group (1/20 [5%] cattle vs 16/20 [80%] cattle).[87] In Brazil in 2004, another study[88] was performed to evaluate the use of fipronil as a 1% topical pour-on preparation applied along the dorsal midline of cattle for the prevention of NWS infestation of castration wounds in cattle. The treated and control groups of cattle in that study had considerable levels of fly strikes, but only 5 of 100 (5%) treated cattle developed active myiasis by day 28 after exposure to NWSFs, compared with 73 of 100 (73%) control cattle. An application of fipronil was 100% effective in eliminating myiasis in the affected animals.[88]

Two avermectins have been studied fairly extensively for prevention and treatment of screwworm myiasis: doramectin and ivermectin. Two studies[89,90] were performed in which calves were injected SC in the lateral midline of the neck with doramectin (200 µg/kg [91 µg/lb]); wounds were created in the animals, and first instar NWSF larvae were applied at rates of 30 and 50/wound within 2 hours of doramectin treatment. At that dose, doramectin was 100% effective in eliminating all first instar larvae within 48 hours of treatment and infestation and was effective in preventing infestation when larvae were applied at 14 days after doramectin injection in one of the studies[89] and 21 days after doramectin injection in the other trial.[90] In a third evaluation[91] investigating the persistence of activity against myiasis, the same dose of doramectin reduced myiasis by 90.9% and 83.3% when 100 larvae were

applied to wounds on days 12 and 15 after doramectin injection, respectively.

Two of the evaluations of doramectin's ability to eliminate NWSF larvae involved comparisons with ivermectin. In 1 trial,[90] 3 of 6 calves treated with ivermectin had active lesions at 48 hours after infestation with NWSFs. In the other study[91] comparing the prophylactic efficacy of doramectin and ivermectin, 2 brands of ivermectin had no greater efficacy than physiologic saline solution based on there being no significant difference in the number of calves with myiasis among the ivermectin-treated groups and the control group. In contrast, results of 2 studies[92,93] involving only ivermectin, injected SC in the neck in a dose of 200 µg/kg, indicated that the drug is highly effective against development of myiasis. In 1 study,[92] none of the calves treated with ivermectin developed myiasis under natural exposure conditions, whereas 4 groups of calves utilized as controls exhibited myiasis in the following proportions: 3 of 12, 8 of 18, 5 of 10, and 8 of 15 calves. Results of the other study[93] indicated that calves treated with ivermectin had significantly less navel and scrotal myiasis than untreated control calves under natural exposure conditions.

The efficacy of ivermectin against OWSF-associated myiasis in cattle has also been assessed. Results of 1 study[94] conducted in Papua New Guinea indicated that a single dose of ivermectin (200 µg/kg) administered SC behind the shoulder in experimentally infested cattle had a residual effect for at least 14 days. This was judged to be an adequate period during which castration wounds would heal and become unattractive to the OWSF.[94] In East Malaysia, SC administration of 200 µg/kg of ivermectin provided 10 days of protection in newborn calves, during which time the navels of the calves dried and were no longer attractive as oviposition sites.[86]

On the basis of these data, there is an apparent difference in the assessed effectiveness of ivermectin against the development of screwworm myiasis in cattle. One reason for this difference may be related to the method of exposure. Natural exposure via oviposition by NWSFs was used in the trials in which ivermectin was determined to be effective.[86,92–94] In the other trials, all exposure was achieved via manual placement of first instar larvae directly into the wounds. Perhaps findings of additional studies will shed further light on the relative effectiveness of doramectin and ivermectin in preventing myiasis in livestock.

In humans, ivermectin has also been used successfully for treatment of NWSF-associated myiasis. Ivermectin administered orally at a dose of 200 µg/kg was reported to be effective in treating oral and orbital myiasis in humans.[46,53] People with auricular, orbital, and cutaneous myiasis have been treated successfully with a topical application of 1% ivermectin in propylene glycol.[47]

Sukarsih et al[95] have investigated the development of a vaccine to control OWSF larvae. Results of their in vivo experiments indicate that there is a 45% decrease in larval weight in vaccinated sheep. In countries where SIT is not feasible or is just being initiated, vaccination of livestock could be beneficial by decreasing the number of flies produced from each egg mass, thereby lowering the overall population of flies in an area.

It was serendipitous when the island of Curaçao became reinfested with NWSFs in 1975[68] because researchers were seeking an isolated area in which to assess the effectiveness of a new technique for reducing NWSF populations. The screwworm adult suppression system is a bait-toxicant system (which can be dispersed from airplanes) that attracts and kills large numbers of NWSF adults. As in the original SIT experiment,[60,61] an area was needed that could not be readily reinfested by migration of flies from adjacent areas; once again, Curaçao was an ideal location. The screwworm adult suppression system units were distributed over a 2.5-month period in 1977; on the basis of trapping data, their deployment decreased the fly population by 65% to 85%. At that point, an SIT was initiated, and eradication was achieved in October 1977.[69]

Present Risk to the United States and Australia

The military action in Iraq, combined with the presence of OWSFs in that region, increases the risk that the insects may be transported to new territories as troops are evacuated. Of the coalition countries with troops still in Iraq, only the United States and Australia have environments that can support a sustainable population of OWSFs. In military personnel, wounds (ranging in extent from major to innocuous) may harbor OWS larvae. However, on the basis of the Panamanian experience, the risk may not be high for transportation of OWS larvae by humans. Of 254 wounded servicemen evacuated from Panama to the United States for treatment, only 1 was confirmed to have been infested with NWS larvae.[8] A greater risk may be posed by the military working dogs in the country[96]; wounds in these dogs could also transport the pest, if proper examination and treatment protocols are not followed prior to relocation.

Other animals that could pose a threat are the numerous "rescued" dogs and cats that are being brought to the United States from the war-torn areas. Several postings on the World Wide Web (5 of which are referenced here[97–101]) report the rescue of domestic animals from Iraq and Afghanistan by members of the US military and others associated with the conflicts. Because these actions are contrary to General Order 1A,[102] the sometimes clandestine methods of shipping used to send the animals to the United States[101] could result in the introduction of disease or parasites, such as OWSFs. One may assume the same type of animal rescue activities may be occurring among the Australian troops, thereby posing a threat to Australia's livestock industry.

During the evacuation of troops and US personnel from Panama, the military had a protocol for examination and treatment of all animals returning to the United States.[103] Although military dogs serving in Iraq are subject to stringent health checks and quarantine[d] and some of the animals rescued from the war zones are properly examined and treated,[98,100] at least one of the latter category appears to have escaped the level of scrutiny that is essential for the detection of unwanted

diseases and pests.[101] Military and private veterinary practitioners must be alert to the possibility of the presence of OWS larvae in animals being shipped stateside or to Australia from Iraq.

Humans and other animals that are transported from the Iraq Theater of Operations need to be evaluated by military medical personnel and veterinarians, respectively, for potential infestations of OWS larvae. If any infestation is suspected, proper treatment must be applied. In affected humans, all larvae must be removed and a specimen submitted to an appropriate laboratory for identification.[79] In animals, ivermectin has been used in dogs and horses to kill fly larvae in an attempt to eliminate any undetectable infestations.[74,103] However, if an infested wound is detected in an animal arriving in the United States, all larvae must be removed from the lesion and a specimen submitted to a USDA-approved laboratory for identification. A protocol similar to that outlined by the Texas Animal Health Commission for animals arriving from Panama in 1999[9] should be followed. The wound must be treated with an approved insecticide (eg, coumaphos) and notification made to the state animal health agency or the state office of the USDA APHIS Veterinary Services. The state or federal animal health officials will provide guidance on quarantine and treatment of the animal and assess the need for treatment of the areas the animal has occupied.[9] A similar protocol should be in place in Australia for the early detection of any imported myiasis cases from Iraq.

Summary

The NWSFs and OWSFs pose threats to the livestock industry of the United States and other countries. Amongst others, private veterinary practitioners are on the frontline of surveillance for these 2 parasites within the United States.[7,9,11] In addition, military veterinarians abroad serve an important role by being in a position to evaluate animals prior to their shipment stateside[103]; their counterparts in the United States and other coalition countries, especially Australia, must examine every animal on arrival to ensure that it has not developed signs of myiasis during transit.

The requirement of the US military, instituted during the Panama Canal shutdown,[103] that all military working dogs and pets of armed forces members receive a predeparture SC injection of an avermectin at 300 µg/kg (136 µg/lb; except in avermectin-sensitive breeds) must be continued for animals being shipped stateside from overseas areas affected by screwworms. Consideration should be given to expanding the requirement to all non–avermectin-sensitive dogs coming from affected areas. In addition, consideration should be given to the requirement for a predeparture SC injection of an avermectin for all livestock from affected areas, not just horses.

Clinical evaluation of any animal that has originated in an area in which NWSFs or OWSFs are endemic should include a thorough examination for wounds that potentially could harbor the larvae. Likewise, livestock owners, especially those importing livestock and those with herds or flocks in areas bordering Mexico, should be reminded to be vigilant for possible cases of myiasis. Larvae from any animal with myiasis must be submitted to an appropriate laboratory for identification, as the rancher in Edwards County, Texas, did in 1998.[73]

It cannot be emphasized enough that diligence on the part of veterinarians and veterinary technicians in private practice and the military is essential for the protection of the US livestock industry. Military veterinarians and technicians stationed overseas have an especially critical role in assuring that all animals are examined and treated prior to departure according to established protocol. Stateside military and private practice veterinary personnel must be diligent to detect any incursion of these exotic pests at the earliest stage, thereby preventing the dispersal of pupae and the establishment of a self-sustaining population of screwworm flies of either species. The USDA APHIS Veterinary Services veterinarians and animal health technicians at ports of entry and quarantine stations are in a key position to detect myiasis in imported livestock; if cases are reported, the priorities of state and federal animal health personnel must be specimen collection, premises inspection, and treatment of animals and environments.

Physicians, physician assistants, nurse practitioners, and nurses within the armed services and in private practice also need to be alert for myiasis in humans returning from areas where either of the screwworm flies is endemic and must submit any larvae recovered from such lesions for identification.[79] Our livestock industry and public health status are only 1 undetected case of myiasis away from potential disaster. Diligence is the order of the day.

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